ANL/ESD/05-1

Suggestions for a New Vehicle Choice Model Simulating Advanced Vehicles Introduction Decisions (AVID): Structure and Coefficients

prepared by
Center for Transportation Research
Energy Systems Division
Argonne National Laboratory

Argonne National Laboratory is managed by
The University of Chicago for the U. S. Department of Energy

About Argonne National Laboratory
Argonne is managed by The University of Chicago for the U.S. Department of Energy under contract W-31-109-Eng-38. The Laboratory's main facility is outside Chicago, at 9700 South Cass Avenue, Argonne, Illinois 60439. For information about Argonne and its pioneering science and technology programs, see www.anl.gov.

Availability of This Report
This report is available, at no cost, at http://www.osti.gov/bridge. It is also available on paper to U.S. Department of Energy and its contractors, for a processing fee, from:

U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831-0062
phone (865) 576-8401
fax (865) 576-5728
reports@adonis.osti.gov

ANL/ESD/05-1

Suggestions for a New Vehicle Choice Model Simulating Advanced Vehicles Introduction Decisions (AVID): Structure and Coefficients

by
D.J. Santini and A.D. Vyas
Center for Transportation Research, Energy Systems Division, Argonne National Laboratory

August 2005

CONTENTS

CONTENTS (CONT.)

CONTENTS (CONT.)

TABLES

TABLES (CONT.)

FIGURES

FIGURES (CONT.)

FIGURES (CONT.)

NOTATION

ACRONYMS AND ABBREVIATIONS

AEO	Annual Energy Outlook
AFV	Alternative Fuel Vehicle
AMFA	Alternative Motor Fuels Act
ATV	advanced technology vehicle
AVCM	Advanced Vehicle Choice Model
AVID	Advanced Vehicles Introduction Decisions
CAFE	Corporate Average Fuel Economy
CEC	California Energy Commission
CV	conventional vehicle
DFV	dual fuel vehicle
DOE	(United States) Department of Energy
DOT	(United States) Department of Transportation
DVL	definitely, very likely, or likely (to purchase a hybrid or diesel)
E85	motor fuel containing 85% ethanol
EIA	Energy Information Administration
EPACT	Energy Policy Act
EPRI	Electric Power Research Institute
EV	electric vehicle
FCV	fuel cell vehicle
FFV	flexible fuel vehicle
FWD	front-wheel drive
HEV	hybrid electric vehicle
HOV	high-occupancy vehicle
LDV	light-duty vehicle
LPG	liquefied petroleum gas
M85	motor fuel containing 85% methanol
MC	make/model combination
MNL	multi-nominal Logit
NEMS	National Energy Modeling System
NG	natural gas
NGV	natural gas vehicle
NPV	net present value
NT	new technology

OPBA	Office of Planning, Budget, and Analysis
ORC	Opinion Research Corporation International
OTT	Office of Transportation Technologies
PEM	polymer electrolyte membrane
PNGV	Partnership for a New Generation of Vehicles
QM00	Quality Metrics Analysis for the Year 2000
SUV	Sport Utility Vehicle
VMT	vehicle miles traveled
ZEV	zero (tailpipe) emissions vehicle

ACKNOWLEDGMENTS

Funding for this study, which is gratefully acknowledged, was provided by Dr. Philip Patterson of the Office of Planning, Budget and Analysis, under the Assistant Secretary for Energy Efficiency and Renewable Energy within the U.S. Department of Energy. This version of the report has benefited significantly from reviews and comments by Steve Plotkin, Dr. Patterson, Margaret Singh, and four external reviewers: Drs. Amanda Miller, Chris Kavalec, Thomas Adler, and Toshiyuki Yamamoto. In particular, we would like to thank Steve Plotkin and our external reviewers for critical comments on content and helpful suggestions with text, including several paragraphs that we have incorporated with relatively small changes. We thank our technical editor Kevin A. Brown, Technical Services Division (TSD), for editing the report and word processing specialist Vicki Skonicki (TSD) for preparing the manuscript. Although several persons have helped make this report complete, the authors are solely responsible for its contents.

SUMMARY

The Advanced Vehicles Introduction Decisions (AVID) model is designed to portray the way in which consumers change their vehicle purchase decisions as new-technology vehicles move from the "risky" or "unique" phase immediately after they are first introduced in the market to the "safe" or "mainstream" phase when they begin to widely penetrate the market. This change in purchase behavior by consumers reflects both their changing perception of the vehicles as their market shares increase and the reality that consumers who are most likely to buy newly introduced vehicles are quite different from those likely to buy mainstream vehicles. For example, a buyer of a new, highly fuel-efficient type of vehicle may be (1) a consumer who drives far more miles per year than the average driver or (2) an "early adopter" who relishes owning a unique vehicle with brand-new technology. This buyer may be less concerned about purchase price than the average buyer and may place a substantially higher value on the characteristics that make the vehicle unique — for example, its high fuel economy. AVID is designed to reflect such differences.

S-1 MODELING APPROACH

At its core, AVID uses a logit model to predict consumer preferences. Logit models use a weighted score for individual vehicle technologies and predict shares on the basis of the relative value of a technology's score. In this case, "technology" means (1) conventional gasoline powertrain versus (2) contemporary hybrid powertrain, but the model is, in principle, generic, and the next version of AVID will likely encompass diesel powertrains, possible future grid-connectable hybrids, and/or fuel cell vehicles. A score is the sum of products of coefficients and values assigned to vehicle technology attributes, such as price, fuel cost per mile, acceleration, top speed, range, and luggage space, among other parameters. A "coefficient," through a set of equations and specified relationships, predicts an implied (or buyer-perceived) dollar value per unit of change of a vehicle attribute.

AVID explicitly recognizes the strong differences among phases of a vehicle's market lifetime and types of buyers. At present, the model develops consumer preference coefficients for two groups of buyers *and* specifies the coefficients for one of these two groups (a minority) to vary as market share changes. The set of coefficients that vary is designed to initially represent the behavior of a set of consumers termed "early adopters" and then to evolve to represent a set of consumers termed "early buyers" of the new vehicles. The combination of early adopters and early buyers is termed the *early group*. The actual size of this evolving early buyer group is uncertain and a topic for future research. However, the initial assumption used for the cases illustrated in this executive summary is that this early buyer group represents about 15% of the buyer population. The second set of coefficients represents the majority of buyers — in the test case illustrated, 85% of the buyer population. A somewhat subtle point is that this model is intended to represent preferences of new vehicle buyers, not used vehicle buyers. The importance of this distinction and its role in determining consumer survey designs and estimating appropriate logit model coefficients is also a subject that could benefit from additional research.

A fully developed version of AVID could be considered as an alternative to the current vehicle choice model used in the National Energy Modeling System (NEMS). NEMS uses a single set of decision coefficients that represents all buyers, and these coefficients do not vary with time since technology introduction or market share. As a result of the investigations discussed in this report, we are concerned that the current NEMS modeling approach may not adequately portray consumer behavior at low market shares. Because market entry is the first hurdle that a new technology must overcome, this process must be characterized properly if the pathway to mass-market success is to be understood. In particular, according to our estimates, the coefficients used in the NEMS vehicle choice model (i.e., the AVID majority buyer coefficients) lead to an estimate that a vehicle with the characteristics of the initial 2001 model Toyota Prius would be unsuccessful in the marketplace. However, AVID would estimate that the 2001 Toyota Prius would attain a modest market share, which better reflects its actual market behavior to date.

At a theoretical level, this study attempts to reconcile troubling differences in implied consumer purchase behavior for light-duty motor vehicles that result from large, unexplained differences between stated-preference surveys and revealed-preference studies. A stated-preference survey is one that asks consumers what they would do if faced with product choices considerably different from those available in the market at the time of the survey. Revealed-preference studies examine how consumers have really behaved, given the existing mix of products available in the market. The Energy Information Administration (EIA) has considered simulation of consumer purchase behavior within NEMS according to use of either stated preference or revealed preference and has made an "either/or" choice, presently using coefficients consistent with the results obtained by synthesis of information from revealed-preference studies.

In this report, we do discuss the merits of using one or the other type of coefficients and conclude that if the "either/or" constraint is imposed, the correct decision is to choose the revealed preference. However, in preliminary tests of sets of coefficients compatible with either stated preferences or revealed preferences, we concluded that neither set could, with present theoretical methodology, accurately depict the pathway to market success of a rapidly evolving, eventually cost-effective advanced powertrain technology. Instead, our approach attempts to make use of existing survey research that is based on the assumption that the fundamentals of existing choice theory are valid. Although we respect the existing theoretical approach behind logit models and use it for the two key consumer preference sub-models, the aggregate modeling method deviates from some present theoretical fundamentals and implies that the proper application of present theory should be researched.

We suggest using a new approach for a vehicle choice model that (1) retains the core "net present value" approach of the current model but (2) introduces the idea of coefficients that vary as market share changes — but not in the pattern implied by existing theory for logit models. The new approach adopts coefficients similar to those used in the present EIA's NEMS and implied attribute dollar values as the proper reference point for most buyers at high market share (because the data from which they are derived were taken at similarly high share levels). Those coefficients are developed from a survey of stated-preference and revealed-preference studies

(Greene and Chin 2000). The analysis conducted to develop coefficients ultimately recommended to EIA rejected the use of coefficients from stated-preference studies.

However, in the AVID model, market entry during initial low-share market conditions relies on the use of coefficients and attribute values presumed to represent a minority of buyers particularly receptive to new and/or better technology — the "early group." The coefficients that actually support the introduction of the technology are thus derived from stated-preference surveys (Tompkins et al. 1998 and the California Energy Commission [CEC] survey [2003] by Morpace International, as well as some surveys by the Opinion Research Corporation) that were directed at new technologies at low-market-share levels. Each of these surveys also included descriptions of technologies considerably different from present conventional technology — including projected increases in fuel economy associated with advanced technologies that span the values attainable by the current (second U.S. generation) Prius. Revealed-preference studies cannot ascertain consumer preferences for future technologies considerably different from those actually available to consumers. The stated-preference surveys used here were conducted when the technologies were either not yet marketed or were available in only limited quantities and for only a short period. The use of different coefficients for the early group is also supported by the use of other information demonstrating a probable distribution of preferences (e.g., data on the distribution of vehicle miles driven among the total driver population).

Moore (2002) explains differences in product evaluation processes of various buyer subgroups. Moore subdivides buyers as innovators, early adopters, early majority, late majority, and laggards. According to Moore, innovators — a small group of buyers — pursue new technologies vigorously, and their endorsement becomes an important tool for early adopters. Our early adopters group consists of Moore's innovators and early adopters, and our early buyers group is behaviorally equivalent to Moore's early majority. Together, they form the "early group."

We recognize, however, that the respondents to the stated-preference surveys represent a wide range of potential purchasers — that is, they are not restricted to members of the early group (early adopters and early buyers). Given this attribute of the available surveys, the coefficients derived from them represent an initial set meant to evolve as more information is obtained and further research on variation of preferences by subpopulation is conducted.

With regard to variation of preferences by subpopulation, the CEC-Morpace study (2003) is of considerable interest because it implies very different coefficients and attribute values for households with greater than $50,000 of income than those with less. Similarly, although age is not a variable in AVID, Kavalec (1999) has shown, for an earlier stated-preference study, that the coefficients (preferences) vary significantly with age of respondent. These findings challenge the idea that use of a single set of coefficients, for a presumed single population, is an appropriate way to model consumer preferences.

The "high market share" majority group coefficients could also evolve as additional data are obtained, but the assumption here is that the certainty about them is greater. Therefore, they are held constant at this time.

Some key features of the suggested model are:

- Expectations of vehicle producers — developed theoretically through an analysis of stated-preference information about candidate new technologies — are the basis for vehicle introduction. The model is programmed in such a way that actual production and sales during the introductory phase lag the potential market (see Rogers 1983 and Mahajan and Peterson 1985 for a discussion of modeling potential versus actual adoption). The potential market is a measure of consumer propensity to buy if an adequate number of vehicles were available with projected vehicle attributes.

- The estimate by vehicle producers of the potential market is a function of the attributes of the technology that they believe they are able to produce. As the market expands and the technology evolves (improves), the estimates of the potential market expand and intentions to produce increase. Once the technology "plateaus," then potential share stabilizes, and actual production is simulated to catch up and match it. The model can, in certain circumstances, predict initial success with early adopters, followed by a shrinking share as early adopters become satiated and early buyers begin to dominate. In effect, the rate at which attributes improve with experience and production volume has to be sufficiently rapid to capture early buyers, after early adopters, or the share can actually drop back to zero. The rotary engine introduced decades ago by Mazda is an example of a powertrain technology that went through such a sequence of events. "Displacement on demand," which is now reentering the market, also failed after initial introduction and testing by high-income customers of Cadillac over two decades ago. Further, in the example herein, it is shown that improvement in the technology is a critical factor in moving from early adopters to the majority market. In the case of Cadillac's V8/6/4 engine, it proved to be unreliable, and this problem was not solved. Thus, early adopters probably did not recommend the technology to early buyers.

- As total market share increases over time, the early group/low-market-share coefficients move toward the majority buyer/high-market-share coefficients moderately rapidly and then become relatively stable. Stability is reached, if the analysis time horizon permits so, after attribute values have declined by a set of user-specified fractions of the initial difference between early adopter and majority buyer attribute valuations.

- At low market share, the early group in AVID is characterized as far less sensitive to vehicle price than the buyers in the EIA's NEMS. This characteristic initially reflects the willingness of early adopters to buy unique vehicles at a reasonably high price premium; later, the higher average income and annual driving characteristics of early buyers push a viable technology further.

- In the Greene and Chin (2000) model, the fuel-cost coefficient is based on the logic that a buyer could not possibly be willing to pay more for fuel savings than the dollars saved per vehicle for an average amount of vehicle travel per year. However, the suggested coefficients for the important minority early group within the new model are based on the idea that (1) most of the earliest buyers purchase a high-efficiency vehicle for a combination of altruism and "bragging rights" and (2) others later place a higher value on fuel cost and other key vehicle attributes because they drive far more than the average buyer. In particular, this yields a much higher early, low-market-share value ($1,800) (attributed to a fuels savings of one cent per mile) than the Greene and Chin (2000) formulation ($475).

- At low market shares, the new model also places a higher value on vehicle performance than does the Greene and Chin (2000) model. For example, acceleration for the early group is initially assigned a value 5 times as high as that for majority group, and it eventually drops toward the Greene and Chin value.

- The modeling approach is a proposal that offers a richer description of consumer behavior during the introduction of a new transportation technology than does the approach it is intended to replace. Because of this richness, users must make many judgments in implementing this new approach. Many of those judgments could be refined or revised as a result of future research that should be done, if this approach seems logically plausible.

- One question raised by the model approach is whether a successful technology *must* first succeed with early adopters. Do these buyers act as leaders and risk takers who "shake out" the new technology and assure its quality and economic desirability for the more risk-averse buyers who follow?

- Although much of this study is generic in its implications, we have dedicated specific effort to develop coefficients appropriate for hybrid electric vehicles (HEVs). We include new variables that allow market share to be affected by such characteristics as the right to use a high-occupancy vehicle (HOV) lane (presently granted to hybrids in the Washington, D.C., area) and the ability to provide backup power for a house (a potential future feature).

S-2 MODEL BEHAVIOR

Figures S-1–S-6 illustrate the model's behavior under some test conditions. These results are for the first-generation vehicle choice model programmed into an initial test version of the modeling approach. The behavior of a final model may vary in detail, but it should not vary in terms of general characteristics illustrated in these figures. The example provided is for competition between hybrid electric and conventional powertrains in a small car and assumes a fuel price of $1.50/gal.

Figure S-1 shows the exogenous assumptions about the relative attributes of the hybrid powertrain. The only relative improvements simulated over time are hybrid price and reductions in fuel consumption. The range of the hybrid is consistently greater than that for a conventional vehicle (CV), while top speed and luggage space are consistently lower. Acceleration remains the same. The hybrid data imply that a hybrid powertrain can, by 2015, enable a 75% increase in fuel economy at an incremental cost of about 7% of the conventional vehicle's cost.

The shape of a price-reduction curve with increasing production volume and years of production experience is usually assumed to involve relatively rapid early declines, followed by reduced rates of improvement in later years, until improvement finally stops. The plot of vehicle price in Figure S-1 shows a continuous decline for several years, and then an abrupt leveling off. The real pattern, however, is likely to involve a series of relatively discrete steps, as different versions of the technology are sequentially introduced. AVID at this time does not include a price decline model as a function of production volume and years of experience, and we recognize that this is a deficiency and briefly address it in Section 7.4. The shapes of the two exogenously specified attribute improvements in Figure S-1 are, therefore, admittedly stylized. However, their joint discrete end in 2015 is useful in subsequent graphs (in this summary and in Section 8) to help conceptually illustrate the point at which one important phase of the technology introduction sequence has been completed. The resulting 2015 "kink" in market share curves shows up in several graphs in this summary and in Section 8.

In Figure S-2, the change of value of attributes as a function of time is illustrated. The model is set up at present to allow users to specify a number of years over which early adopters dominate the early group choice values, which is followed by a presumed drop in interest by

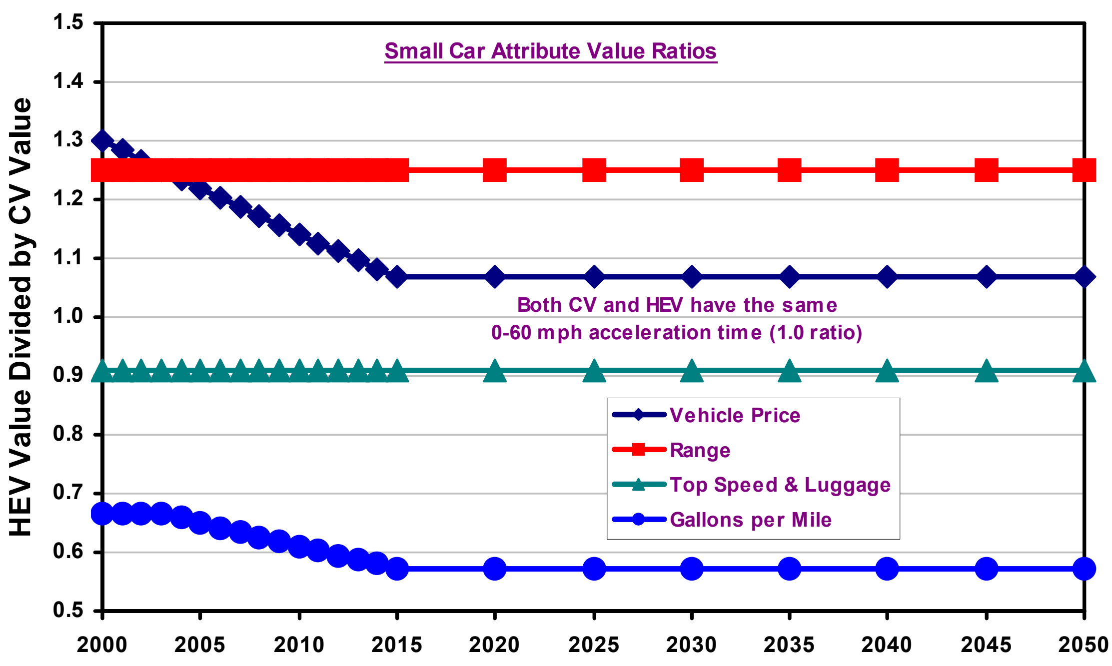

FIGURE S-1 Hypothetical Relative Merits of a Hybrid vs. Conventional Powertrain in a Small Car

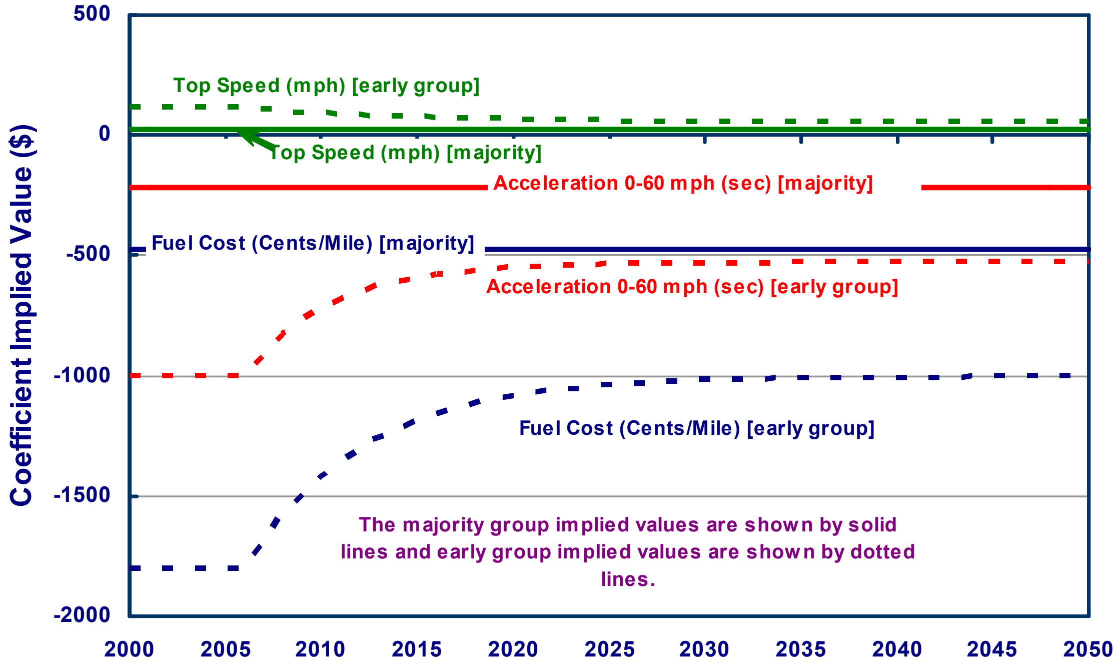

FIGURE S-2 Evolving Dollar Values of Attributes as a Function of Time

early adopters. The modeling approach assumes that as early adopters drop out of the market, the appropriate attribute valuations shift toward the type of buyer we call early buyers. For the early group (consisting of early adopters and early buyers), the user, therefore, specifies a rate of decay of preferences from early adopter values toward early buyer values. This illustration shows that, following an exogenously specified six years after (year 2000) market introduction of the new hybrid powertrain technology, the early group exhibits a sharp decline in its willingness to pay more for higher fuel economy (reduced fuel cost in Figure S-2), acceleration (reduced 0–60-mph time in Figure S-2), and top speed.

Figure S-3 illustrates the interactive effects of overall preferences for the new technology as it is made available in the market and evolves in terms of technical and economic characteristics over time. Figure S-3 shows estimates of the *potential market* (HEV combined), not the actual market.

- In Stage 1, the early adopters are far more interested in purchasing the new powertrain technology in the first six years after introduction, but interest after six years is simulated to drop rapidly. From initial introduction to year six, consumer propensity to buy actually increases because early group coefficients are held constant while the vehicle attributes improve. Note that the improvement in vehicle attributes is only adequate in the first six years and draws a mere 0.2% of the majority buyer group into the potential market.

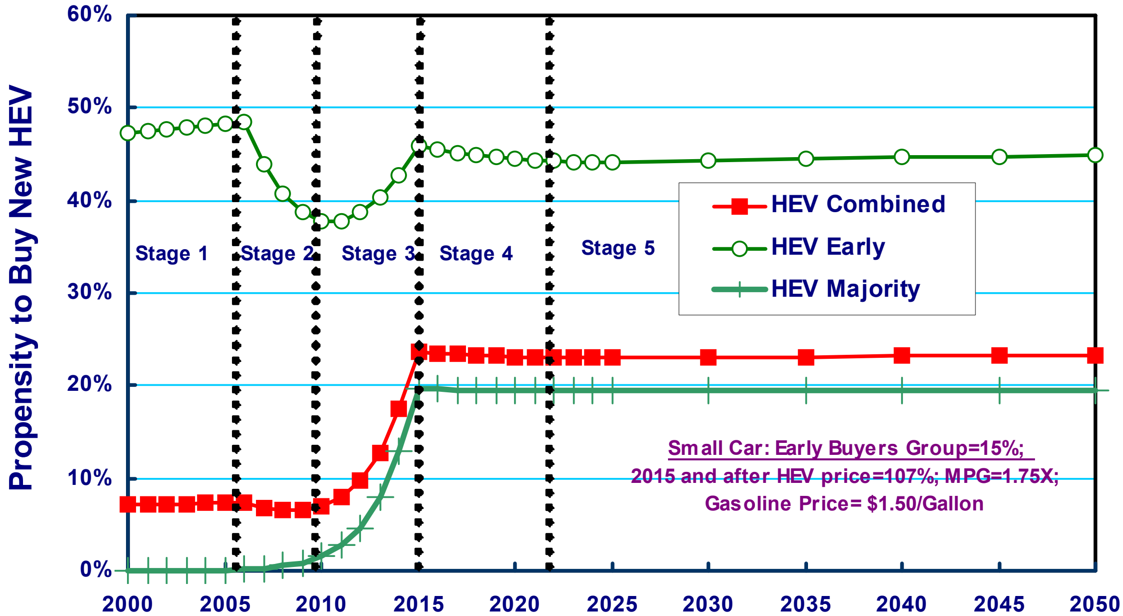

FIGURE S-3 Share of Customers Willing to Buy if Enough Cars with Specified Attributes Were Available

- In Stage 2, for the years 2007 and 2008, the total potential market actually shrinks as the exit of early adopters causes the share representing the early group to drop more rapidly than rate at which the share representing the majority group increases. From 2006 to 2010, the exit of early adopters is simulated to cause the share representing the total early group to shrink, despite consistent improvements in the technology.

- However, in Stage 3, from 2011 to 2015, the rate at which attribute valuations of the early group change (i.e., move from early adopter model coefficients to early buyer coefficients) is less rapid than the effect of improvement in the technology, and the share representing the early group is therefore simulated to rise because of technology improvements.

- In Stage 4, after 2015, the positive effect of vehicle attribute improvements stops. The early group's willingness to pay for the superior attributes of the technology continues to decline slowly thereafter, so that the propensity of the early group to buy is simulated to decline slightly through 2022.

- After 2022, in Stage 5, market shares are stable.

The importance of the early group (and its proper simulation) to the ultimate success of the technology is illustrated by the estimate that the early group represents over 95% of the potential market through 2007 and over 50% through 2012. In the long run, the simulation implies that recognition of the early group in the model only raises the potential market size from

19% to 23%. Nevertheless, without the early group's high propensity to be the first to buy (thereby creating an incentive to get the technology started), a new technology might not get introduced.

Figure S-3 illustrates the preliminary AVID model estimate of what share of hybrids *could be* sold, given the specified technical attributes and history of availability. However, it is not an estimate of how many are *actually* sold. A producer introduction model is combined with the estimate of potential market to create an estimate of actual sales of the vehicles. The combined effects of the consumer preferences model and the producer response model are illustrated in Figure S-4. Despite the marked fluctuations in aggregate consumer propensity to buy in the potential market during the fist decade and a half, the modeled delays of producers in reacting to this emerging potential market cause the actual market result to be a relatively smooth prediction of the increasing share of the new vehicle market represented by hybrid vehicle production. Such a pattern of technology introduction is common in history. The classic example of a manufacturer delaying introduction despite emerging consumer propensity to buy more advanced technology is the continued production of the Model T Ford in the 1920s as GM replaced Ford as the number-one manufacturer.

The model implies that the share of the market attained by the first producers to sell the technology will expand, while for producers that delay or refuse the production of the technology, market share will shrink. However, the model also implies that success is not guaranteed if the path of improvement of attributes is uncertain.

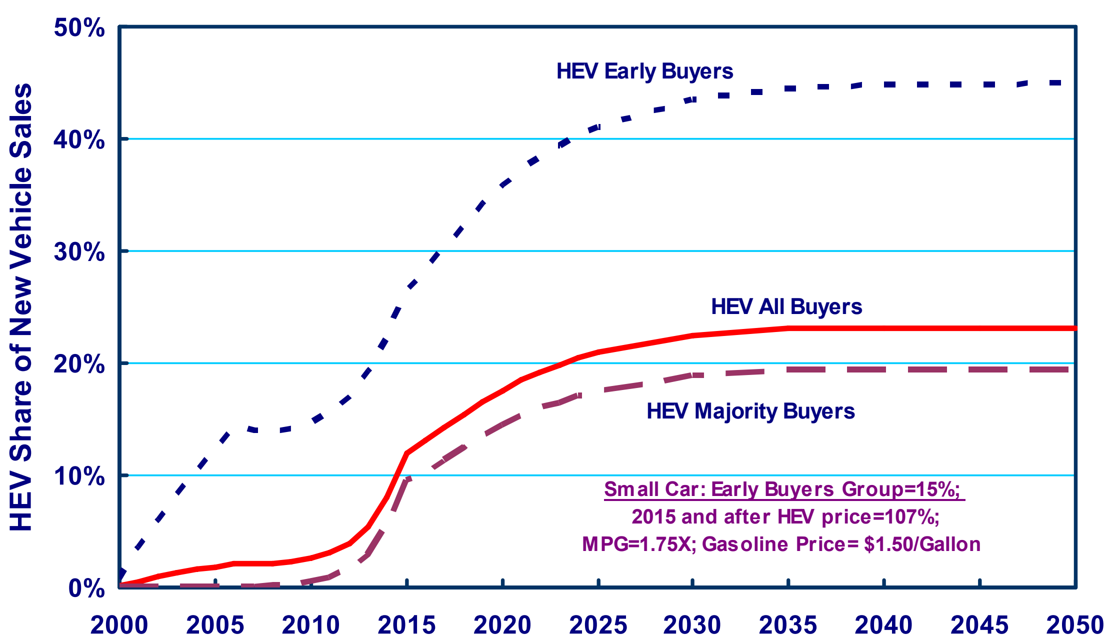

FIGURE S-4 Share of New Car Market Held by the Hybrid, Given Vehicle Production Decisions

Figure S-5 illustrates more clearly the total market paths over time. Once the technology attributes have been simulated to have stabilized, and the majority buyer market supersedes and overwhelms the initial spike in interest by early adopters and early buyers, the actual number of vehicles produced converges to a relatively stable share of the market, representing fulfillment of the potential of the technology.

Note that the relatively smooth growth path for hybrids could be altered if gasoline prices fluctuated. The simulations illustrated here are based on constant fuel prices of $1.50/gal. One reason for building producer-related delays into the model is that the effects of rapid, dramatic fluctuations in fuel prices need to be damped down. In reality, producers cannot — and do not — quickly react to dramatic, potentially reversible changes in consumer preference that are associated with rapid changes in fuel price, which are uncertain. One effect of the lag structure in the producer decisions model would be to require that fuel prices remain elevated for several years before production plans would be significantly altered. Eventually, according to the AVID structure, producers "catch up" and match their production levels to the propensity of consumers to buy, and a stable market share is achieved.

This simulation implies that interest in the technology by majority buyers would surpass that by early buyers between 2010 and 2015, before the simulated technological improvements have stabilized in 2015. On the basis of this simulation, majority buyers appear to begin to be interested in the technology when it achieves the degree of success shown in about 2010. The technological improvements (reduced price and fuel consumption) projected from 2010 to 2015 are simulated to make a great deal of difference to majority buyers and to lead to fairly significant, but not sweeping, market success.

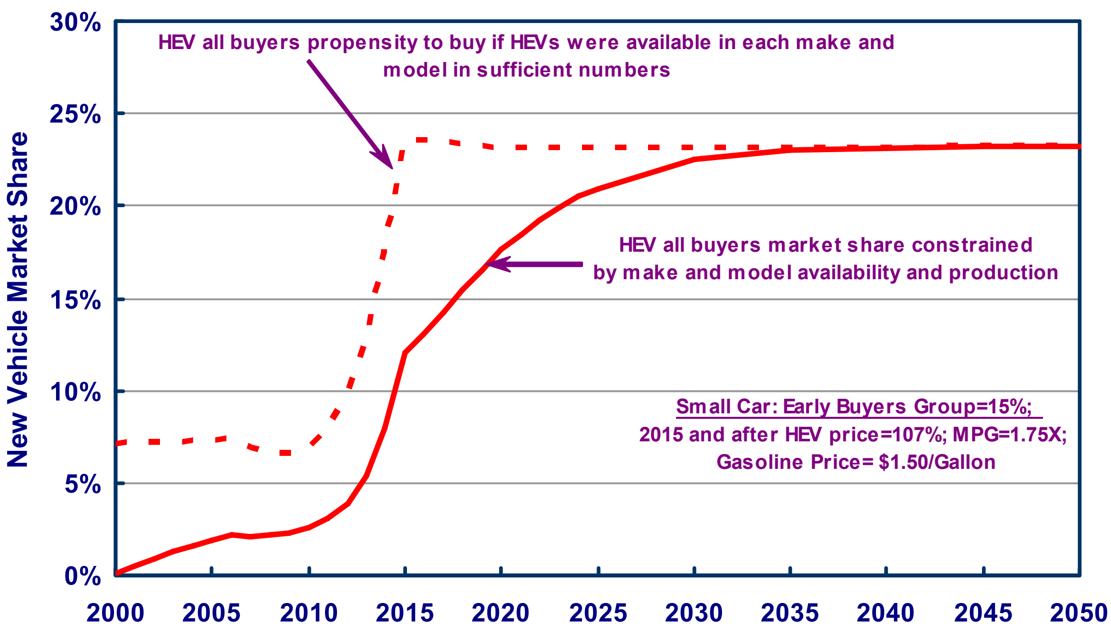

FIGURE S-5 Potential (Unconstrained) vs. Actual Share of Total Small Car Market Held by Hybrids

The examples of the working of the model shown in Figures S-1–S-5 are, of course, for a specific set of circumstances. We have noted that the criticism of stated-preference models was that they were too sensitive to fuel price and too insensitive to vehicle price. In the long run, this model, like NEMS, does simulate a population of customers who are predominantly sensitive to vehicle price and less sensitive to fuel price. This phenomenon is shown in Figure S-6, which illustrates the effects of a series of vehicle price and fuel price experiments. Aside from the constant \$1.50 gasoline price scenario in Figures S-3–S-5, the effects of a high-gasoline-price scenario are illustrated in Figure S-6. Under this scenario, gasoline price was slowly increased to \$3.00 by 2008. Also shown in Figure S-6 are two cases where the HEV price increment over the CV was increased to 18% by 2015 instead of 7%.

Simulations were carried out for the two-gasoline-price and HEV-price-increment scenarios. If the HEV price increment does not drop from 18% to 7%, and if gasoline prices fall to \$1.50 per gallon (a figure experienced in the 1960s and mid-1990s), then HEV sales are predicted to shrink to perhaps 1% from a peak of about 3% attained within a few years. In contrast, for a hybrid vehicle to achieve an increase in market share to about 57%, the price per gallon of gasoline must be doubled from \$1.50 to \$3.00 and vehicle cost increment held at a constant 7%. As an analogy, the transition to front wheel drive from about 1979 to 1988 (see Section 7.3.1) suggests that this initial version of the model may be a bit too responsive to gasoline price increases in terms of rate of change of share. On the other hand, U.S. gasoline prices have never risen to \$3.00/gallon and stayed there.

Note that the lowest cost (retail price) increment for a hybrid powertrain that has been estimated and published with input from the authors of this report is 12% for a “low-drag, reduced mass” mid-size car (Graham et al. 2001). This vehicle — similar in several respects to the 2004 Toyota Prius — was also simulated to have an increase in fuel economy of 80%, so it

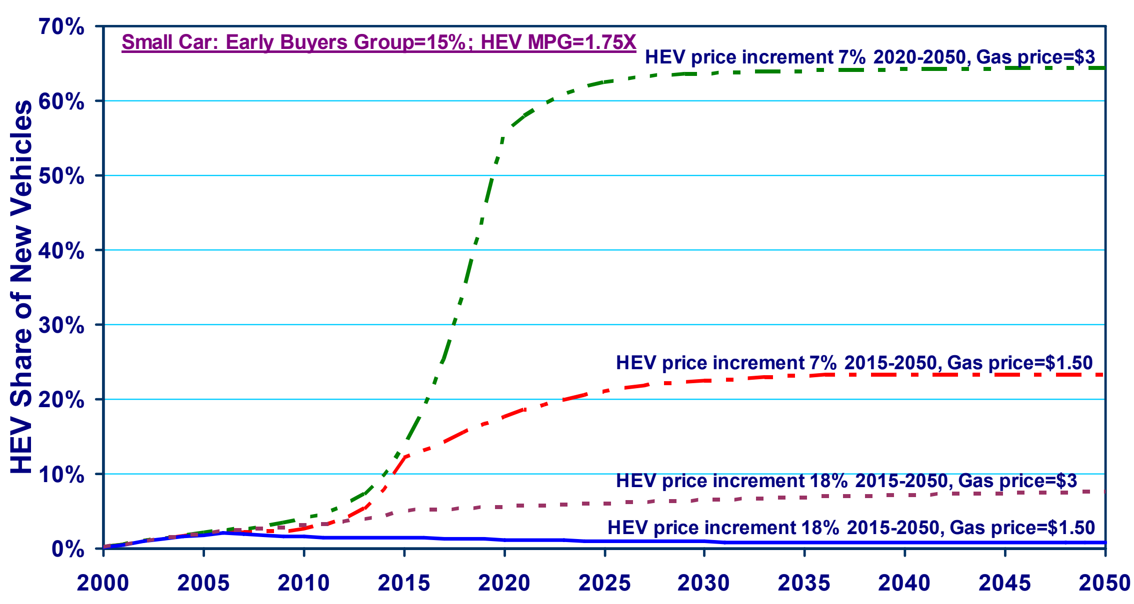

FIGURE S-6 Small Car HEV Market Shares from AVID Tests

was comparable to the cases simulated here, which have a 75% increase in fuel economy. However, since that estimate, the 2004 Prius has demonstrated component attributes that may lead to even lower costs than estimated in that study. Further, versions of hybrids to be introduced in 2005 will have four-wheel drive, for which the hybrid technology appears to be cost-effective (EEA 2002). Thus, an incremental cost of less than 12% in conjunction with a fuel economy increase of about 75% may be possible in the next few years for HEV configurations in some small and mid-size cars, although some may consider the 7% base case to be optimistic.

The cost of attaining greater fuel efficiency through hybridization is partly a matter of perspective and, in reality, is quite difficult to determine. Suppose that manufacturers of front-wheel-drive mid-size cars and small sport utility vehicles (SUVs) wish to provide the acceleration of a V8 engine within their existing platforms. Empirical information suggests that achieving V8 performance is very difficult because a large V8 engine is not easy to fit transversally in a FWD-vehicle configuration. Consequently, V8 engines are found mostly in rear-wheel-drive vehicles; smaller ones are sometimes used in front-wheel-drive vehicles. With a conventional powertrain, there is a fuel economy penalty for switching from front- to rear-wheel drive, but the powertrain type is also less expensive. A manufacturer could retool factories and convert its models to rear-wheel drive to be able to fit V8 engines into the vehicles. Retooling a factory is expensive; even so, some manufacturers have done this. DaimlerChrysler introduced the highly successful "300C" car, in which a V8 "hemi" engine can be installed in this new rear-wheel-drive model.

Another alternative is to provide an optional hybrid powertrain in an existing front-wheel-drive architecture that is more powerful than the most powerful V6 sold. Honda has pursued this alternative in its Accord, and Toyota has pursued this approach in its Lexus RX400 and Toyota Highlander hybrids. By using existing front-wheel-drive platforms, Honda and Toyota avoid the costs associated with retooling the production lines for conversion to rear-wheel drive for these highly successful models, but they are able to provide V8-level acceleration to compete with manufacturers that choose to do what DaimlerChrysler did — while also increasing fuel economy dramatically. For these cases, the cost of hybridization should be compared with the cost of installing a more powerful conventional engine in the same platform. Because installing such an engine is very difficult, the cost comparisons might actually look very good. It is beyond the scope of this study to consider these cost trade-offs at this time. However, we present the logic so that those familiar with the comparisons made in the past may understand that our low estimate of 7% incremental cost may actually be attainable — depending on the structure of the comparison made.

As illustrated in Figure S-6 and by the comments in the preceding paragraph, the long-term potential of the hybrid vehicle powertrain is promising, although uncertain. Vehicle price increment and future gasoline prices seem to be key factors, the values of which could cause a wide range of eventual long-term market shares for hybrid powertrain technology. At present, early buyers and unexpectedly higher oil prices have prompted several automakers to produce hybrid powertrains to further test the consumer's response and their ability to refine the technology.

An important caveat concerning these results is that they are preliminary and do not include competition from diesel and fuel cell powertrains. Since this report was reviewed, we have conducted survey research to attempt to confirm and quantify the characteristics of this study's three buyer types (early adopters, early buyers, and majority buyers); that research also compared markets for HEVs and diesels. We have also reviewed market prediction research and techniques outside of the transportation literature. A discussion of some of the findings of that research is included in Appendix A. That research was also peer reviewed (by blind review); a more limited discussion than in the appendix was published in the CD-ROM of the 2005 Transportation Research Board Meeting. Logical next steps are to (1) develop coefficients for the numerous models of vehicle that are included in the NEMS model; (2) add coefficients for additional vehicle attributes; and (3) add "slots" for more powertrain technologies, such as diesel, grid-connectable hybrids (called plug-in hybrids by many), and/or fuel cell powertrains.

S-3 REFERENCES

S-3.1 Primary References

CEC: California Energy Commission

CEC-Morpace, 2003, *California Vehicle Survey 2002, Final Report*, Morpace International Market Research and Consulting, Farmington Hills, Mich., Jan. 10.

EIA: Energy Information Administration

EIA, 2003, *Monthly Energy Review*, U.S. Department of Energy, Energy Information Administration, Washington, D.C., July.

EEA: Energy and Environmental Analysis, Inc.

EEA, Inc., 2002, *Analysis and Forecast of the Performance and Cost of Conventional and Electric-Hybrid Vehicles,* California Energy Commission Consultant Report P600-02-013CR, March.

Graham, R., et al., 2001, *Comparing the Benefits and Impacts of Hybrid Electric Vehicle Options,* Final Report 1000349, Electric Power Research Institute, Palo Alto, Calif.

Greene, D.L., and S.M. Chin, 2000, *Alternative Fuels and Vehicles (AFV) Model Changes,* Center for Transportation Analysis, Oak Ridge, Tenn. (contract DE-AC05-00OR22725), Nov. 14.

Kavalec, C., 1999, "Vehicle Choice in an Aging Population: Some Insights from a Stated Preference Survey for California," *The Energy Journal* 20(3):123–138.

Mahajan, V., and R.A. Peterson, 1978, "Innovation Diffusion in a Dynamic Potential Adopter Population," *Management Science* 24:1589–1597.

Moore, G.A., 2002, *Crossing the Chasm: Marketing and Selling Disruptive Products to Mainstream Consumers,* revised edition, HarperCollins, New York, NY.

Morpace International Market Research and Consulting, 2003, *California Vehicle Survey 2002. Final Report*, Farmington Hills, Mich., Jan. 10.

National Household Travel Survey 2001, 2003, Bureau of Transportation Statistics and [Online analysis options provided at: http://nhts.ornl.gov/2001/index.shtml. Analysis conducted July 31, 2003], Federal Highway Administration, U.S. Department of Transportation.

ORC: Opinion Research Corporation

ORC International, 1996 and 1997, CARAVAN Services, Surveys of 1000 Households during Oct. 17, 1996, and Oct. 24, 1997, for National Renewable Energy Laboratory, Golden, Colo.

ORC International, 1998, 1999, and 2001, CARAVAN Services, Surveys of 1000 Households during Feb. 19, 1998; Aug. 5, 1999; and Nov. 2, 2001, for National Renewable Energy Laboratory, Golden, Colo.

ORC International, 2003, CARAVAN Services, Survey of 1000 Households during March 15–16, 2003, for National Renewable Energy Laboratory, Golden, Colo.

ORC International, 2004, CARAVAN Services, Surveys of 1000 Households during May 20, 2004, for National Renewable Energy Laboratory, Golden, Colo.

Rogers, E.M., 1983, *Diffusion of Innovations,* Free Press, New York.

S-3.2 Secondary References (discussed by Mahajan and Peterson 1985)

Chow, G.C., 1967, "Technological Change and the Demand for Computers," *American Economic Review* 57:1117–1130.

Dodson, J.A., and E. Muller, 1978, Models for New Product Diffusion through Advertising and Word-of-Mouth, *Management Science* 24:1568–1578.

Hagerstrand, T., 1967, *Innovation Diffusion as a Spatial Process,* University of Chicago Press.

Horsky, D., and L.S. Simon, 1983, "Advertising and the Diffusion of New Products," *Marketing Science* 2:1–18.

Lackman, C.L., 1978, "Gompertz Curve Forecasting: A New Product Application," *Journal of the Market Research Society* 20:45–57.

Robinson, B., and C. Lakhani, 1975, “Dynamic Price Models for New Product Planning,” *Management Science* 21:1113–1122.

Souder, W.E., and A. Quaddus, 1982, “A Decision-Modeling Approach to Forecasting the Diffusion of Longwall Mining Technologies,” *Technological Forecasting and Social Change* 21:1–14.

SUGGESTIONS FOR A NEW VEHICLE CHOICE MODEL SIMULATING ADVANCED VEHICLES INTRODUCTION DECISIONS (AVID): STRUCTURE AND COEFFICIENTS

ABSTRACT

A model for evaluating the market penetration potential and diffusion path of new vehicle technologies is summarized in this report. The model, the Advanced Vehicle Introduction Decisions (AVID) model, applies a new approach by segmenting vehicle buyers as “early adopters and early buyers” and “late majority buyers.” Unlike (1) the current Advanced Vehicle Choice Model used by the Office of Planning, Budget and Analysis (OPBA) under the Assistant Secretary for Energy Efficiency and Renewable Energy within the U.S. Department of Energy (DOE) and (2) the vehicle choice model within the National Energy Modeling System (NEMS), AVID portrays the way in which consumers change their vehicle purchase decisions as new-technology vehicles move from the “risky” or “unique” phase immediately after they are first introduced in the market to the “safe” or “mainstream” phase when they begin to widely penetrate the market. AVID employs separate consumer preference coefficients for the two groups of buyers, and its algorithm causes the coefficients for one of these two groups (a minority of buyers) to vary internally as market share changes. The set of coefficients that vary is designed to initially (at the technology introduction time) represent the behavior of a subgroup of consumers termed “early adopters” and then to evolve within the model to represent another subgroup of consumers termed “early buyers” of the new vehicles. By simulating systemic variation in consumer preferences in conjunction with buyer groups as the market share of new technology expands, the AVID model differs from the current vehicle choice model used in the NEMS, which uses a single set of constant decision coefficients that represents all buyers. Since this report was reviewed, Argonne has conducted survey research to attempt to confirm and quantify the characteristics of this study’s three buyer types (early adopters, early buyers, and majority buyers); that research also compared markets for hybrid electric vehicles (HEVs) and diesels.

1 INTRODUCTION

1.1 BACKGROUND

The U.S. Department of Energy (DOE) currently has two different vehicle choice models to assist policy analysis and decision making about the market penetration potential of advanced technology vehicles. The current Advanced Vehicle Choice Model (AVCM) used by the Office of Planning, Budget and Analysis (OPBA) under the Assistant Secretary for Energy Efficiency and Renewable Energy within the U.S. Department of Energy (DOE) may be regarded as a "shell" amenable to substitution of different coefficients that characterize consumer valuation of various vehicle attributes, such as price, fuel efficiency, acceleration, range, and luggage space, among others. The Energy Information Administration (EIA) within DOE has adopted a set of coefficients in the National Energy Modeling System (NEMS) transportation forecasting model that is radically different from the set of coefficients previously developed as a result of a national stated-preference survey for the predecessor of OPBA. Comparing the coefficients of revealed-preference studies with those obtained in stated-preference studies shows a systemic, large difference between the coefficients obtained, creating a fundamental conflict requiring resolution.

The Center for Transportation Research at Argonne National Laboratory was asked to review the content and status of these two models and recommend an approach that both explains the differences in the current models and improves their outcomes. After extensive analysis of the existing models, we recommend a new class of logit models of consumer choice for advanced vehicles. The information from both classes of studies used in the existing models is, nevertheless, of value, and the cited stated-preference findings are informative about early adopters and "early buyers" of advanced vehicle technology, while revealed-preference studies are informative about the large majority of late buyers who will determine if an advanced technology can capture the market completely. We suggest using different coefficients for separate classes of consumers. These classes of consumers are termed the "early group" and "majority group." The early group is simulated to consist of different subgroups — early adopters and early buyers. Early adopters are simulated to behave differently from other consumers, while early buyers are like majority buyers in their evaluation process, but they have greater reason for high efficiency and high quality in their vehicles (they spend more time in their vehicles and drive more miles per year). For the early group, the coefficients evolve in value from starting "early adopter" values. Then, as early adopters exit the early group and early buyers begin to predominate, the early group coefficients move toward, but do not match, the values based on revealed-preference studies.

On the basis of recommendations made in this report, an initial, abbreviated Advanced Vehicle Introduction Decisions (AVID) model is implemented, and some tests of its behavior are completed. The consumer-preferences portion of the model provides producers with an estimate of consumer propensity to buy, or market potential, if enough advanced technology vehicles were produced to satisfy the demand. The producer introductions model simulates a cautious, lagged introduction of the new technology into the new vehicle market, smoothing out some of the fluctuations in consumer propensity to buy as the technology improves over time and as the market moves from dominance by early adopters, early buyers, and, finally (if improvements of the technology are adequate), majority buyers. Eventually, the producers match production shares to the propensity of consumers to buy, and market share stabilizes if exogenous conditions (such as oil prices) remain unaltered.

1.1.1 History

During the late 1980s and early 1990s, proposed solutions to the problem of U.S. dependence on oil in transportation involved alternative fuel vehicles (AFVs), as promoted in the Energy Policy Act (EPACT) of 1992. Alternative fuels that were of considerable interest when the EPACT was written were methanol, natural gas, and electricity. Earlier, in 1988, another important act, the Alternative Motor Fuels Act (AMFA), was written, the basis of which was the technological feasibility of using flexible fuel vehicles (FFVs) powered by methanol or dual-fuel vehicles (DFVs) powered by natural gas.

Generically, an FFV can run on either of two (or more) liquid fuels in the same tank, in varying mixtures. Early in the 1990s, FFVs capable of running on a blend of methanol and gasoline in an 85/15% volume blend (M85), or gasoline, or any intermediate mix were produced and marketed. AMFA provided a credit under the Corporate Average Fuel Economy (CAFE) regulations that allowed a certain number of FFVs to be produced and sold and credited with double their gasoline test fuel economy (Nichols 2003).

A DFV requires two separate fuel tanks and generally refers to a vehicle that can burn gasoline and compressed natural gas. However, DFVs capable of burning gasoline and liquefied petroleum gases (LPGs) have also been produced. In principle, AMFA also promotes DFVs. However, it often costs multiple thousands of dollars more to produce a DFV than a CV.

Because FFVs can be produced for an incremental cost of $300 or less (Nichols 2003), manufacturers have been able to produce a large number of FFVs and obtain CAFE credits in the late 1990s and early 2000s. However, instead of the methanol (M85) fuel option, these vehicles are designed to be capable of running on a blend of 85% volume ethanol and 15% gasoline-like hydrocarbons (E85). FFVs are largely indistinguishable from CVs, and many consumers today purchase FFVs without even knowing it or ever intending to refuel on E85. In the case of the Chrysler minivan, the vehicle requires more frequent maintenance if the consumer does use E85. Further, very few stations in the nation actually sell E85, and those stations that do usually sell it at a price that makes the cost per mile of operation greater than that for 100% gasoline. Nevertheless, consumers are clearly not reluctant to purchase these vehicles because they do not see any penalty whatsoever, since they are able to use only gasoline if they wish.

In addition to the FFVs and DFVs, manufacturers anticipated that dedicated alternatively fueled vehicles[1] could be produced and could be somewhat more thermodynamically efficient

[1] AFV, in contrast to "alternatively fueled vehicle," is a generic term for a vehicle that uses a fuel different than petroleum, even in small proportion.

than gasoline vehicles. E85 and M85 have higher octane than gasoline, and in a vehicle designed to take advantage of this through dedication to only the E85 or M85 fuel, greater thermodynamic efficiency can be obtained (even though the fuel economy expressed in gallons is lower because of the lower energy content per gallon of E85 and M85 than of gasoline). Natural gas has an even higher octane rating. However, its thermodynamic efficiency potential in dedicated vehicles is considerably offset by heavy fuel tanks, which in some vehicles use up trunk space.

Finally, electric vehicles (EVs) were promoted in the 1990s as a result of "zero emissions vehicle" (ZEV) regulations in California that were scheduled to require automakers to sell up to 10% ZEVs by the present. The vehicle type that was expected to meet this requirement was the EV. EV models were produced and sold on a test basis in California, but they proved to be too expensive and inferior in function. The EVs had limited driving range between refueling, required very expensive batteries, required the replacement of the expensive battery packs during the vehicle's life, and lacked interior volume because of the large battery packs that were needed to obtain adequate range. Although their operating cost per mile was low and their efficiency high, their initial costs were at least $10,000 and higher than for competing CVs. Despite these drawbacks, EV advocates did not seem to understand why the vehicles failed.

When the 1992 EPACT was written, many were optimistic that these FFVs, DFVs, and dedicated AFVs could replace oil use with methanol, ethanol, natural gas (NG), liquefied petroleum gases (LPGs), and electricity. The EPACT anticipated replacing 10% of oil use by light-duty vehicles (LDVs) in 2000 and 30% in 2010. The expected reduction in oil use in 2000 has not happened, and the targeted oil reduction for 2010 will not happen without catastrophic pressures on the U.S. economy.

1.1.2 The Present

For years, the United States conducted research on hybrids designed to make use of battery technology developed for electric vehicles, and often the intent was to plug the hybrid into the electric grid. However, in 1995, at the 31st Tokyo Auto Show, Toyota Motor Corporation introduced a prototype hybrid, called the Prius, in which the battery had been redesigned to produce far more power. Using a redesigned battery pack with a much higher power-to-energy ratio than had been envisioned by U.S. experts, Toyota engineers designed the Prius to be independent of the grid, making use of regenerative braking and onboard electricity generation in such a way that gasoline fuel consumption was sharply reduced, even without the use of electricity from the grid. In 1997, Toyota produced its first-generation Prius hybrid electric vehicle for sale to consumers in Japan. This vehicle runs on gasoline and uses two electric machines (generator/motors) and a small battery pack, along with an efficient engine design made possible by the hybrid powertrain (the Atkinson cycle engine), to accomplish a jump in fuel economy not possible with any combination of non-hybrid CV powertrain technology — known or anticipated. A second-generation model was introduced in the United States in 2000, and a third was introduced in the fall of 2003 (as a 2004 model). Information on the Toyota website indicated that the 2004 Prius had a list price of $19,995. The MSN Auto web site (http://autos.msn.com/) also indicated that the retail price of the 2004 model Prius sold in 2003 was $19,995, and the invoice price was $18,411. Interior volume statistics for the 2004 Prius from Toyota's web site indicated that the 2004 Prius would have a passenger volume almost midway between the compact Toyota Corolla and midsize Camry sedans, while its trunk would be close in the size to the larger Camry trunk.

Pricing the Camry SE and Corolla CE with automatic transmissions, antilock braking systems, and cruise control, to match standard features of the 2004 Prius, leads to estimated list prices (excluding destination charges) of $20,175 and $14,920, respectively, and invoice charges of $18,044 and $13,748, respectively. Since the invoice cost of the 2003 Prius is closer to its retail price than is the invoice cost for a Camry or Corolla, we assume that the more appropriate comparison of costs would be on the basis of invoice prices. On this basis, if one assumes that the invoice price discount for the 2004 Prius is the same as that for the 2003 model, then an estimated 2004 invoice price of $18,793 for the Prius compares with an average 2003 invoice price for the Camry and Corolla of $15,896, which is an 18% difference. An investigation of the "Car True Market Value" on the America On-Line automotive web site (http://www.edmunds.com/new/index.html?mktcat=gnauto&kw=true+market+value&mktid=ga 198436search) revealed that the Camry, Corolla, and Prius all sold for a few percentage points above invoice price and that a comparison on that basis would give similar results.

Thus, the 2004 incremental price was estimated to be in the range of 18% more for the Prius than for the average of the two most comparable CV models on the Toyota showroom floor. Although a vehicle like the Prius was not simulated, Plotkin et al. estimated in 2001 that the long-run incremental cost of a hybrid like the Prius could be as low as 18% more than that for a comparable CV. The gain in rated miles per gallon of the 2004 Prius, through the hybrid drivetrain and other features, will be about 100% compared with the Camry and 66% compared with the Corolla. The battery pack is far less costly than that for an electric vehicle, and discoveries related to battery chemistry and the way in which the battery is used in this hybrid suggest that the battery might last the life of the vehicle for many consumers. This is a vast improvement over preceding, deep discharged, battery packs for electric vehicles.

The United States instituted a program in September 1993 — the Partnership for a New Generation of Vehicles (PNGV) — to produce a mid-size passenger car that would triple fuel economy ("3X" goal). Compared to this ambitious goal, the 2004 Prius increases fuel economy by "only" 88% in comparison with the Camry/Corolla average. In addition to its sophisticated hybrid powertrain, the Prius uses a slightly modified, slightly more efficient gasoline-fueled engine (based on the "Atkinson" cycle) than that in the Camry or Corolla. Because of the need for more powertrain efficiency than is available in the Prius, the diesel engine in a hybrid powertrain was the cornerstone of the PNGV program. During the time of the PNGV program, U.S. "Tier II" emissions regulations passed, which are scheduled to go into full effect over the next few years; these standards introduced a new, lower emissions baseline that made it difficult for the PNGV program to be followed up by production and commercialization of diesel hybrids. With respect to achieving required Tier II emissions levels, the diesel engine has proven to be more challenging than gasoline engines. The 2004 Prius and several other gasoline-fueled vehicles have already demonstrated emissions considerably lower than those required by the coming Tier II standards, using existing gasoline composition.

Potentially helpful to the effort to reduce diesel engine emissions, diesel fuel regulations have been enacted that require the sharp reduction of sulfur within the next few years (reductions are also required in gasoline). The sulfur reduction may create enough of a benefit in terms of emissions control technology to allow diesels to meet "bin 5" of the Tier II standards and perhaps allow diesel hybrids to do even better. Although none are presently scheduled for commercial introduction, this could conceivably result in diesel hybrid mid-size passenger cars capable of between two and three times the per-gallon fuel economy of the 1993 mid-size gasoline passenger cars.

On another technological track, a membrane discovery — nafion — and success in reducing the amounts of platinum required for catalysis made the high-efficiency Polymer Electrolyte (also know as Proton Exchange) Membrane (PEM) fuel cell stack appear promising for automotive use. Ballard, with support from the DOE and Natural Resources Canada, produced several generations of fuel cell stack, steadily improving specific power, power density, and efficiency. General Motors, when it built its diesel hybrid PNGV "Precept" prototype, also built a hydrogen fuel cell mock-up in the same body and touted it as having simulated gasoline-equivalent fuel economy well in excess of the PNGV goal. Several other automakers throughout the world also began working on fuel cell vehicle prototypes. From the California perspective, the hydrogen fuel cell vehicle (FCV) provides a second option to produce a ZEV. Technically, prototype hydrogen fuel cell vehicles appear superior to electric vehicles with respect to range, refueling frequency, and refueling duration. Nevertheless, in these respects, the fuel storage systems of prototype FCVs have been far from the standard set for gasoline, requiring much more bulky, heavy storage systems to achieve the same range and refueling frequency.

2 VEHICLE CHOICE MODELING

2.1 THEN AND NOW

In the 1990s, the question at hand was whether AFVs could penetrate the market at a rate sufficient to meet EPACT goals. Projections were necessary. Since the vehicles that consumers would be expected to purchase to meet the EPACT goals would be very different from CVs and were not in the market, DOE attempted to determine how consumers might react by conducting a stated-preference survey (Tompkins et al. 1998). This survey followed an earlier one done in California and attempted to adhere closely enough to that earlier survey to allow an analysis through a combination of the two surveys. This was accomplished. The DOE surveyed households in the 47 states within the lower 48 outside of California. The combined survey results were, for the most part, similar to those for the 47 states. Notable differences were Californian's stronger preferences for clean and fast cars. The initial publication of the results had been estimated in a fashion to allow duplication of the structure of the estimates in the California survey.

Following publication of these results, on behalf of the EIA, an unpublished re-estimate was completed by Argonne and collaborators. This effort tailored estimates to the NEMS modeling structure at the time and included some additional tests of functional forms of variables (Poyer and Santini 1999). EIA, for reasons discussed below, found the coefficients to provide unacceptable predictions when used in NEMS. EIA therefore commissioned David L. Greene of Oak Ridge National Laboratory, a well-respected expert in revealed-preference surveys, to address the shortcomings of the stated-preference coefficients developed from the Tompkins et al. study (Tompkins et al. 1998). This study was completed by Greene and Chin in 2000, and NEMS was thereafter modified according to the guidance provided by Greene and Chin.

An analytical team within DOE's Office of Transportation Technologies (OTT) used a separate vehicle choice model for much longer-term evaluations and projections of technology success/failure than those conducted by the EIA. Once Greene's work was done and the results implemented in NEMS, the OTT model, used by Dr. Philip Patterson's analytical team, which consists of a group of analysts from national laboratories, retained two sets of coefficients — one consistent with NEMS and the other drawn from the Tompkins et al. work (Tompkins et al. 1998). "Either/or" choices were made between pairs of coefficients, on the basis of professional judgment about the behavior of the model. However, there was not a systematic study of the implications of using the vastly different coefficient values. In part, this study — leading to the AVID model — fills that void.

The largest problem, from Greene and Chin's perspective, was a lack of sensitivity to vehicle price and an excessive response to fuel cost if the related Tompkins et al. vehicle price coefficients were used. Aside from this problem, Greene and Chin worked out some superior functional forms (formulas) for variation of value of range and fuel availability, compared with those in the stated-preference survey experiments conducted for California (Brownstone et al. 1994, Bunch et al. 1991) and subsequently for the United States (Tompkins et al. 1998).

More recently, another stated-preference vehicle choice survey and model development effort was completed during 2002 for the California Energy Commission by Morpace International Market Research and Consulting (Morpace 2003). This survey focused on conventional gasoline, diesel, and hybrid vehicles with capabilities similar to those of the Prius (full hybrids) and did not consider electric vehicles, natural gas vehicles, or flexible fuel vehicles. Hereafter, this survey and modeling will be referred to as the CEC-Morpace Study.

Still another pair of surveys were conducted recently by using a different methodology (Graham et al. 2001; Taylor and Miller 2003). These preference surveys were specific to hybrid electric vehicles. This survey, combined with predictions of hybrid vehicle attributes and prices, led to “base case” predictions that a full-hybrid mid-size car could attain a mid-size segment share of about 35% if (1) hybrid powertrains were only offered in mid-size vehicles and (2) a 27% combined share if hybrid powertrains were also offered in compact cars, small SUVs, and large SUVs. A subsequent study estimated a segment share of 18% for hybrid powertrains in compact cars with different assumptions (Duvall 2002). Survey respondents were residents of one of four major metropolitan areas — Los Angeles, Boston, Phoenix, or Atlanta. Respondents were told that hybrids would not have any penalty in top speed or towing capability, which is not consistent with our expectations. They were told to assume the following:

- Gasoline prices were $1.50–2.00 per gallon;
- Hybrid powertrains were available in all makes and models;
- Hybrid vehicles had been in the market 10 years, were quieter and smoother than conventional vehicles, and had comparable or superior handling; and
- Hybrid vehicles had around-town acceleration of 0–30 mph that was superior to that of conventional vehicles.

These points are consistent with our long-term expectations.

2.2 STATED- VS. REVEALED-PREFERENCE ESTIMATES: ARE THEY INFORMATIVE ABOUT THE SAME CUSTOMER CHOICE BEHAVIOR AT DIFFERENT MARKET SHARES?

Greene and Chin generally dismissed stated-preference results and indicated in their analysis that they did not regard this method of developing coefficients as worthy of serious consideration. Instead, they relied on revealed-preference studies and on deductive logic related to the mathematical properties of the logit model and the “rational man” (or engineering/economic man), according to economic theory. The rational man, in this case, logically evaluates a future stream of costs and benefits and translates them all into a common comparative metric, in order to determine desirability. Here, the common metric is present value dollars, which are compared to the first cost (price) of the vehicle.

According to the model theory as explained by Greene and Chin, if the coefficient for vehicle price in a logit model is known, then the coefficient for any other attribute can be developed by estimating the dollar value of one unit change for that attribute and multiplying this value by the price coefficient (Greene and Chin 2000).

Greene and Chin therefore attempt to evaluate the reasonableness of other coefficients in other studies in terms of the implied present dollar value of a unit change of the attribute. Thus, in the most critical examples, if a coefficient implied that respondents in a particular study placed too high a value on lifetime vehicle fuel savings or lifetime maintenance costs, Greene and Chin were prone to dismiss the coefficient (or ignore the study) and develop their own estimate of what a reasonable consumer would do.

Note that Greene and Chin's method is based on knowledge of preferences of average consumers for today's average vehicles, not in yet-to-be-marketed advanced technology vehicles. They note in their discussion that, because of the properties of the logit model, one must clearly state what market share applies when a coefficient is developed. They then proceed to conduct their coefficient development for a case in which they imply that a vehicle's technology is competing when it theoretically has a 50% share. One conceptual flaw in this argument is that the studies referred to as a basis for coefficients and values are conducted for various models of vehicle with a conventional powertrain. This vehicle technology has nearly a 100% share of the market, not 50%. However, the discussion of the fuel consumption case developed herein implies that the difference between (variable) vehicle price response coefficients from 50% to 100% market share is likely to be far less on a percentage basis than the change from a market share of about 1% through 50% (see Sections 2.6 and 4.2).

A primary objective in using a model to project the introduction of very different technology is to capture the likely preferences of those individuals who can allow the technology to get its first significant foothold in the market (0–15% here). In this report, we argue that these individuals fall into two types — early adopters (those who are quite different in preferences from the majority of the population) and early buyers (those who use the same careful system of choice as most buyers, but differ in their circumstances such that they are more likely to buy early high-fuel-efficiency models than the majority). Taken together, we call the early adopters and early buyers the "early group."

We also note that if new technology will have the ability to provide changes in attributes far outside the range experienced among conventional vehicles, then results based on studies of conventional vehicles must be regarded with skepticism.

The notion that market introduction involves a sequence of groups of buyers is consistent with long-standing theory. F.M. Bass (1980), analyzing refrigerators, air conditioners, dishwashers, televisions, and clothes dryers, also posited two groups in his model. In his 1980 article, Bass noted that E.M. Rogers (various editions) had developed from the literature a five-group conceptual scheme, which was based on timing of adoption:

1. Innovators,
2. Early adopters,

3. Early majority,
4. Later majority, and
5. Laggards.

Bass himself assumed that groups “2 through 5” are aggregated and defined as “imitators.” In our model, the first two categories certainly fit into our “early group,” while those in the “early majority” who drive a lot of miles would probably be included as well. The remainder would be the majority buyers.

In his applied and nonacademic book, Moore (2002) defines a market in the following way:

- A set of actual of potential customers,
- For a given set of products or services,
- Who have a common set of needs and wants, and
- Who reference each other when making a buying decision.

We emphasize “set,” “common needs and wants,” and “referencing” as key in a consumer’s decision process that leads to buying a vehicle. The products in question are such new technology vehicles as hybrid, diesel, and fuel cell vehicles. The sets are early adopters, early buyers, and majority buyers. The emphasis on referencing helps explain why, even though Kurani et al. (2004) and Kurani and Turrentine (2004) have demonstrated that few consumers can do net present value (NPV) calculations, the early buyer and majority buyer market could, nevertheless, exhibit the behavior of the rational buyer.

Moore’s (2002) sets of consumers are the same as those of E.M. Rogers, as noted by Bass: innovators, early adopters, early majority, late majority, and laggards. Our mapping is roughly:

- Early adopters = innovators and early adopters,
- Early buyers = early majority, and
- Majority buyers = late majority.

Laggards are simply ignored, as Moore recommends. With regard to understanding how to get a new product into the market and determining how successful it can be, laggards are essentially unimportant. Moore characterizes innovators as a very small group of the population. “Innovators pursue new technology products aggressively. …There are not very many … Their endorsement reassures the other players.”

Early adopters are a larger group, but like innovators, they do not make decisions “pragmatically.” “Because early adopters do not rely in well-established references in making buying decisions, preferring instead to rely on their own intuition and vision, they are key to opening up any high-tech market” (Moore 2002, p. 12). However, Moore also states that for early adopters, “…the endorsement of innovators becomes an important tool” (p. 14).

Thus, on the basis of Moore's arguments, the early adopter group that we seek to characterize would include his innovators, who influence his early adopters, and neither of these groups makes pragmatic decisions. Our argument is that it is largely the presence of these respondents in stated-preference surveys that distorts the statistical results, making the results seem implausible to those who wish to understand the majority of the market —the pragmatists. Note that the stated-preference surveys cited here each attempted to determine consumer reaction to a technology very different from the mainstream technology — a situation by its nature that should excite and interest innovators and visionary early adopters. In the absence of new technologies, this group would have behaved like the pragmatic majority.

Revealed-preference surveys, on the other hand, characterize the existing majority market. If conducted at a time when no radical innovations are being attempted, the mix of technologies from which consumers may choose will be relatively narrow. Consequently, the results should be very similar for most consumers, who will behave like pragmatists and choose among similar technologies. We suggest that, in the absence of a new technology within such a market, early adopters will simply behave like majority buyers.

Moore argues that visionary early adopters are incompatible with pragmatic majority buyers. Moore states that "early adopters do not make good references for the early majority" (early buyer in our terminology).

Kurani and Turrentine (2004), surveying a number of potential vehicle buyers, found that only a very small fraction were able to even approximately compute the net present value of fuel cost savings. They conclude, therefore, that the rational model of consumer behavior is implausible. Because this is the foundation for the behavior of majority buyers and much decision making in government, it is desirable to determine whether the findings are valid and if the rational buyer model should be thrown out or its use greatly curtailed.

Moore (2002, p. 20), a proponent of using the "Technology Adoption Life Cycle," discusses the problem of marketing to the "early majority" (our early buyers) after succeeding with the early adopters. In discussing the challenge of getting a technology started within the majority market and making the difficult transition across the "chasm" from the early adopter market, he states for the early majority, "good references are critical to their buying decisions. So what we have here is a catch 22. The only suitable reference for an early majority customer, it turns out, is another member of the early majority … no upstanding member of the early majority will buy without first having consulted with several suitable references." Elsewhere, he describes the majority of consumers as "*pragmatists* in orientation."

Our "solution" to the problem posed by Kurani and Turrentine (2004) is to explore the hypothesis that once the pragmatic majority buyer decides that a technology is interesting, that buyer seeks out other scarce, but important, expert pragmatists to acquire the information needed to make an intelligent (where use of NPV is defined as intelligent) decision on whether to make a purchase. Thus, the assertion is that the fact that buyers do not know how to use NPV analysis is not important — what is important is that they know where to find information from someone who does do NPV analysis.

Moore's late majority and our majority buyer category may be called "conservatives." They "will not support high price margins. Nonetheless, through sheer volume, they offer great rewards to the companies that serve them appropriately" (Moore 2002). In our case, the reason that the majority buyer does not support high price margins is that they are not fascinated with the technology of the car (like innovators), nor do they need the car as much as early buyers. Thus, they can more easily choose to spend their money elsewhere than on outstanding features for their household vehicles.

In reality, the model desired by DOE should be one capable of capturing consumer preferences of all groups of interest — early adopters, as well as early and majority buyers. An ideal model might actually have variable coefficients that change in a way thought to mimic the different preferences or needs of these groups. It can be argued that Greene and Chin's approach is reasonable for majority buyers — those upon which a full transition from one transportation technology to another must depend. However, it is not likely to capture attributes of early adopters and early buyers.

We have carefully chosen the term "early buyers" and wish to distinguish it from "early adopters." We assume that the latter have significantly different preferences from the majority of consumers. David Hermance of Toyota recently (Hermance 2003) asserted that early adopters represent only about 3% of the market. He indicated that Toyota is interested in an "early majority" rather than in an early adopter. We use the term early buyer rather than early majority. However, we believe that the point is the same: that the buyers who will make a vehicle technology successful evaluate vehicles according to the same logical rules as the majority of consumers. For various reasons, these buyers are unusual in respects that prompt them to make decisions that are different from those made by the majority of buyers. According to Moore, they use references in making their buying decisions. Nevertheless, we hypothesize that their evaluation *process* is the same as that of majority buyers. In particular, for hybrid vehicles, we assume that the early buyers will be individuals who drive far more miles per year than the typical vehicle owner (or far more hours per year — see Santini, Patterson, and Vyas 2002). We also examine the possibility that these buyers might have higher incomes than average new-car buyers (who are assumed to have higher incomes than average used-car buyers).

In this analysis, we pursue the hypothesis that stated-preference surveys for advanced vehicles do contain meaningful information. We assume that the results of the survey have been influenced by the combination of early adopters and early buyers, and that the coefficients that result from them could be used (with some modifications) to represent the preferences of this subset of the population. We argue that it is these customers who are the most likely to allow advanced technology vehicles to successfully enter the market. To the best of our knowledge, none of the surveys conducted have tested the hypothesis suggested here.

However, some testing should be possible — if funds were provided to authors of prior studies and if those authors have retained the survey data. For example, we believe that the Tompkins et al. (1998), CEC-Morpace (2003), and Graham et al. (2001) studies each collected information on the miles typically traveled by respondents. It should be possible to (1) test whether respondents who drive a lot were significantly different from those who do not with respect to valuation of fuel consumption and (2) examine such study respondents in comparison with the general population. In the CEC-Morpace study, researchers attempted to obtain responses from those intending to purchase new vehicles, rather than the general population. In principle, for proper comparison to the results of the CEC-Morpace study, revealed-preference studies should be sorted, and only those that examine new car buyers be used for comparison. Households that buy new cars generally drive more miles than those buying used cars.

The consumer preference survey in the Graham et al. (2001) study actually included questions designed to identify probable early adopters, but no results were reported on tests done to examine whether this subgroup had a lower concern about price and greater interest in other vehicle attributes. The survey asked those interested in the mid-size vehicle to rank the most important reasons for buying a hybrid. Acceleration, which was listed as important by 55% of respondents, was listed far behind vehicle price (91%) and fuel cost savings (89%). Attention/pioneer image was listed by only 33%. Our position here is not necessarily that the number of households that regard acceleration or "attention/pioneer image" as highly important is large. Instead, we believe that the preferences of this minority of households are quite important in determining stated-preference coefficients, and future research should attempt to determine the degree of that influence.

Given our hypothesis about the value and nature of information from stated-preference surveys, we use both sets of coefficients developed by Greene and Chin (2000) and by Tompkins et al. (1998) We construct a composite model with both (1) two sets of coefficients and, within one of these sets, (2) coefficients that vary in response to evolving market success of advanced vehicle technologies.

Bass (1980) cited "contagion" models from epidemiology in his development of a technology diffusion model with asserted innovators and imitators. He posited significant interactions between the two groups, choosing the name of the majority of buyers (imitators) to emphasize a lead role for the early group. Bass also assumed evolving and changing consumer preferences. In his model, the basic premise "is that the probability that an initial purchase (adoption) will be made … given that no purchase has yet been made is a linear function of the number of previous buyers."

We do not implement such an assumption in this model, which is fundamentally different from Bass' diffusion model. However, we do concede that there could be some interaction between the preferences of the two groups and some evolution of preferences over time.

The notion of systematically varying coefficients is, in fact, consistent with logit model theory, which is a foundation within this study. Greene and Chin (2000) point out that the elasticity of response in the logit model is, according to theory, not a constant. The *theory* suggests that the appropriate coefficient is a function of share of the market and steadily drops from its highest value as one moves from 0% to 100% share. They state:

> *The most important coefficient in a vehicle choice model is the coefficient of purchase price. In effect, the price coefficient serves as a scaling factor for all other variables in the model. In a multinomial logit model, the price elasticity of market share, β_p, is not constant, but depends on the current market share, s, and*

on the price level, P, as follows: $\beta_p = \upsilon P(1\text{-}s)$. Thus, price elasticity will approach a maximum of υP as s nears 0 and approach 0 as s nears 1. For this reason, price elasticities of different models should be compared at constant price and market share.

The last statement deserves further evaluation. The statement that *models* should be compared at constant price and market share is valid and important. However, it is not possible to compare stated-preference and revealed-preference *study* results at constant price and market share because they are, in fact, done at different prices and shares. Tompkins et al. (1998) and CEC-Morpace (2003) stated-preference studies were done at different vehicle price increments (larger), fuel economy increments (larger), and market shares (smaller) than prior revealed-preference studies. In terms of the theoretical argument above, stated-preference study price coefficients relative to revealed-preference coefficients are consistently theoretically incorrect.

Importantly, our empirical investigations provide information that explains why real-world deviations from the above theoretically posited relationship of price elasticity and share apparently exist, consistent with the low-vehicle-price elasticities obtained in stated-preference studies. Reiterating, revealed-preference studies of contemporary technology and stated-preference studies of hypothetical advanced technologies cannot be compared as if they apply at the same (constant) market share because they, in fact, do not. Greene and Chin (p. 19) dismiss the Tompkins et al. study by asserting that their vehicle price coefficient was far too low and could not be correct when evaluated at a 50% share. The key point is that the stated-preference surveys for advanced vehicles should be interpreted as if they represent some respondent behavior at a small market share. The stated-preference studies conducted by Tompkins et al. and their predecessors (Bunch et al. 1991; Brownstone, Bunch, and Golob 1994) and the recent CEC-Morpace successor should be evaluated as if they are influenced by early adopters and early buyers, while those reviewed and used by Greene and Chin should be evaluated as if they are influenced by majority buyers.

This point, however, does not resolve the problem of inconsistent coefficients — according to theory, it exacerbates it. Therefore, another important point is that our investigation in this report finds contradictory evidence to the prediction that the highest price elasticity occurs at the lowest share (a mathematical fine point here is that we actually refer to the *absolute value* of elasticity, not the actual elasticity, which is a negative number). Our investigation suggests that the *lowest price elasticity at lowest share* is probably the appropriate description of real consumer behavior when a new technology is introduced. If correct, this suggests that the theory should be modified to take into account real-world deviations from its implications, when new technology is entered into the market. This assertion is not trivial, because economic theorists are not receptive to deviations from presumed rational behaviors.

In fact, in the stated-preference surveys, consumers were asked about vehicles that were not yet in the market at all. In the Tompkins et al. study, respondents were asked to evaluate fuel availability for alternative fuels from 5% to 25% of the conventional fuel market and to consider numbers of comparable vehicles "in their region" in terms of thousands. We doubt that the respondents envisioned a marketplace in which 50% of the AFVs offered were of the type being considered. Further, respondents were asked to consider several *types* of AFVs, as well as numerous conventional vehicles, and so the mental image of the share of any single type of AFV under consideration would have had to be far below 50%.

Greene and Chin (p. 8) state that "the choice between very different AFVs, such as a flex-fuel gasoline-alcohol vehicle and a battery electric vehicle, should be less price elastic because of significant other design differences between the vehicles." Thus, they imply that the price elasticity of distinctly different alternative technologies trying to enter the market should be lower *among themselves* than against conventional vehicles. However, it seems logical that if a single new technology is distinctly different from a conventional vehicle, this same argument should imply a lower price elasticity.

2.3 SIMULATED VS. THEORETICAL ELASTICITY VARIATION

When the AVCM model was tested with Greene and Chin vehicle price coefficients, a vehicle price variation of plus or minus 20% was found to be sufficient to change share from about 1% to 99% (Santini and Vyas 2003).

When estimating an elasticity of response of share to price change, we found that the elasticity derived from the model's behavior varied dramatically as a function of share, as the theory that Greene and Chin [YEAR] stated predicts (see Figure 1). The pattern of consistently and steadily declining market share with increasing incremental cost shown in Figure 1 is hereafter termed a behavior associated with a "rational buyer" model. By definition, if consumer surveys result in patterns of share change inconsistent with those shown in Figure 1, some survey respondents are "irrational" in the classic economic sense.

To evaluate the theoretical pattern of behavior of elasticity cited by Greene and Chin, we examine in Section 4.2 (compare Figure 8 with Figure 1) a logical deductive pattern of market penetration based on an assumption that consumers use net present value estimates of the benefits of fuel savings. We find that the behavior of that model is reasonably consistent with the theory as expressed by Greene and Chin. This exercise also implies a Figure 1-like pattern of rational response of consumers to surveys that can be contrasted to their actual responses.

On the basis of theory and that logical exercise, one would conclude that the Greene and Chin position on stated-preference results is valid. However, we also reexamine some relatively simple surveys and note a behavior at low market share that is quite inconsistent with the theoretical model of Greene and Chin and the logical behavior examined in Section 4. The confounding factor is hypothesized to be the early adopter, in contrast to the early buyer. We observe that the combined effect of early adopters and early buyers is likely to cause a sharp decline in elasticity of market share as a function of incremental vehicle cost vs. fuel savings at low market shares, early in the introduction phase for a new technology.

This is potentially the key contribution of this study — essentially a plausible explanation for the large differences in estimated coefficients in stated- and revealed-preference studies. We admit that an explanation would benefit from future research designed to isolate the influence of

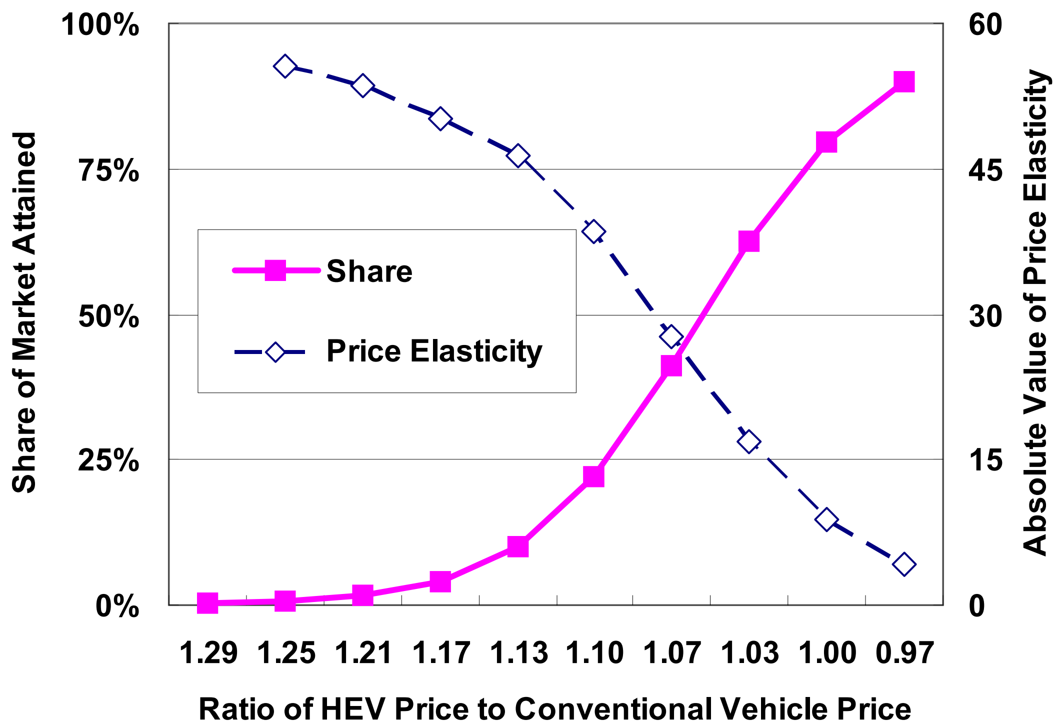

FIGURE 1 Elasticity of Small Car Market Share to Purchase Price (AVCM Test with Greene and Chin Coefficients)

presumed subgroups of respondents, thereby statistically isolating their influence on estimated model coefficients. Following the review of the initial draft of this study, we conducted a survey that was designed, in part, to test whether respondents intending to purchase hybrids appeared to be "rational" or "visionary." Results are presented in the appendix. The latter description appeared more apt, supporting the notion that visionary early adopters are critical to hybrid vehicle success (Santini and Vyas 2005).

2.4 EARLY ADOPTERS, EARLY BUYERS, AND MAJORITY BUYERS

2.4.1 Early Adopters — Who Are They?

Thus far, we have discussed a model of behavior for two categories of buyers that we call early buyers and majority buyers who rationally evaluate the purchase decision. We also have discussed a third type called the early adopter and need to consider how the early adopter might influence the statistical results that we seek to reevaluate. Our hypothesis is that early adopters and early buyers are quite different consumers. Early buyers hypothetically use the same decision process as majority buyers, but they do their evaluations under personal situations that differ from those of the typical majority buyer (they drive more miles and have higher income, in particular). However, early adopters probably buy for entirely different reasons. Such buyers may be fascinated with technology or may have philosophical reasons for wanting to reduce oil use.

The early buyer of the first hybrid vehicle, the Honda Insight, was clearly not purchasing the vehicle just to save fuel. This vehicle is a small, sleek-looking two-seat car made largely of aluminum. J.D. Power (Malesh 2000) found that an unusually large proportion of Insight buyers actually bought the vehicle as an additional household vehicle rather than as a replacement vehicle. Although the fraction of all buyers who add a vehicle, according to Power, was 19% in 2000, the fraction that added the Insight was 43%. Even if the Insight were compared with "sports cars," it still exceeded the 29% adding vehicles for this category. In fact, the Insight was relatively unique even among other two-seaters, most of which could legitimately be called sports cars. It had far lower acceleration capability than any of these vehicles and did not offer a convertible option, which many of the two-seaters include.

Honda advertised the Insight as a virtuous "green" vehicle. Malesh (2000) concluded that low emissions and outstanding fuel efficiency were clearly the focus of consumer interest. Malesh noted that 86% of Insight buyers said fuel economy "was extremely important" versus 44% among all new vehicle buyers. This finding was consistent with Hermance's 2003 characterization of the earliest Prius buyers — more than 80% of them highly valued fuel economy, which is a percentage that is higher than that for any class of conventional vehicle. Unfortunately, neither Malesh nor Hermance reported the miles driven by Insight and Prius buyers relative to all new vehicle buyers. In any case, for those who added the Insight, one might speculate that there was actually the intent to drive more household miles than before. Malesh did note that the second most important attribute of the Insight cited by its buyers was the nebulous response: "they just liked the vehicle."

Retrospective consideration of the hybrid powertrain introduction strategies of Honda and Toyota suggests that both companies judged the early adopter to be an individual who would prefer a unique vehicle. They may have designed vehicles with this buyer in mind, in order to get the hybrid powertrain into the market and refine it before targeting it at majority buyers. In both cases, the initial hybrid powertrain was placed in a completely new vehicle body that did not have a conventional powertrain available. However, as the two companies seek the majority buyer, they are offering (or will offer) the powertrain as an option in one of their existing vehicle model lines. Honda produced a hybrid version of its highly successful Civic model after the unique Insight, and in December 2004, it introduced a hybrid version of its best-selling Accord. Toyota is producing yet another version of the unique Prius, but announced in 2003 that the hybrid powertrain would be an option in several standard models in the future (Toyota Motor Corp. 2003).

2.4.2 Willingness to Pay "Too Much" to Double Fuel Economy

In reviewing three available surveys for number of respondents willing to spend a specified number of dollars for a vehicle that doubles fuel economy, we identified an interesting property of three surveys. In Figure 2, we reproduce the figure and reconfigure the results of a

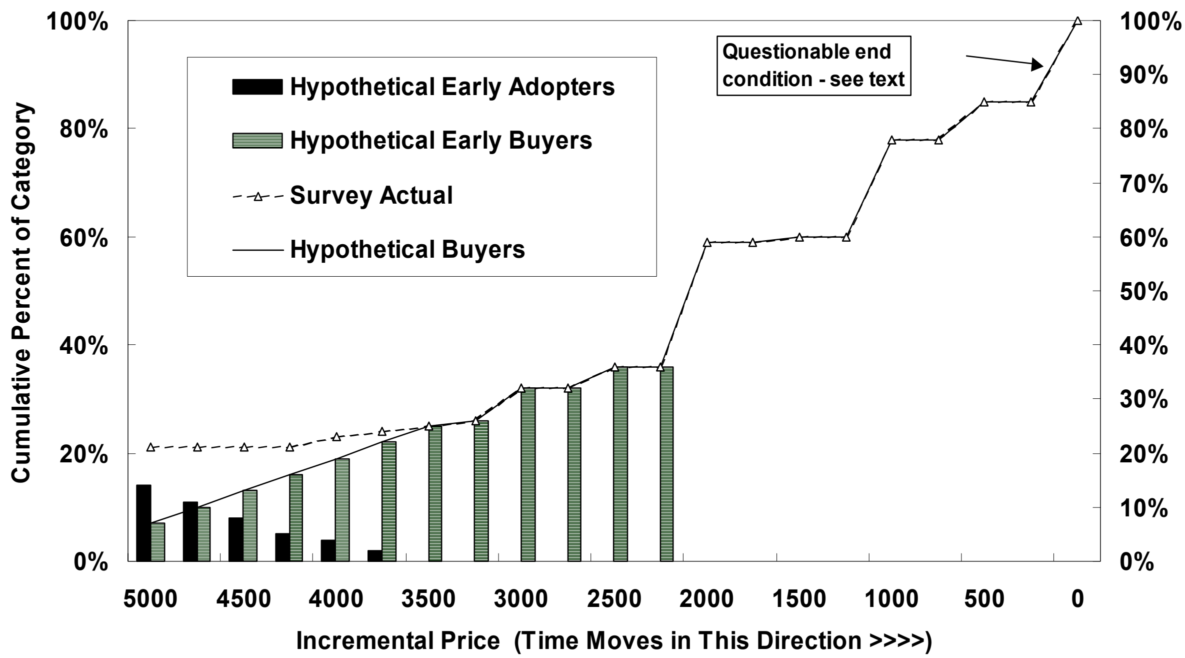

FIGURE 2 Willingness to Pay for Double Fuel Economy — Survey Results and Buyer Group Hypotheses (Heim 1999)

survey cited in the report by Heim (1999) titled "Assessment of Current Knowledge of Hybrid Vehicle Characteristics and Impacts." The figure reporting the results of this survey is titled "Willingness to Pay for Double Fuel Economy." Cumulative market share attained is plotted on the vertical axis as percent of respondents indicating a willingness to purchase at a specified incremental vehicle price. The point to be highlighted first is the flat 21–25% share totals from about $5,000 incremental cost to $3,250. This total can be contrasted with the slowly rising and lesser share totals for the highest cost segment of Figure 1.

Because there appears to be a larger number of willing buyers at high incremental costs than is implied by standard theory, we construct estimates of a separate class of buyer called the early adopter. Roughly, this hypothetical class of buyer will purchase a vehicle with double fuel economy because of stronger preferences for fuel economy than would be indicated only by net present value accounting. If this potential buyer is asked what he or she would pay for a unique vehicle with an attribute not presently available in the market, this buyer type is presumed to be far more likely than the majority buyer to answer that the unique vehicle will be purchased at a higher price. Thus, when stated-preference surveys are conducted that ask about unique vehicles not in the market, the inclusion of these respondents is expected to confound the standard economic model of consumer behavior, simply because they have a non-standard set of preferences when a nonstandard vehicle emerges. It must be stressed that these respondents are not providing misleading answers. Their preferences can be used as a means of testing a unique vehicle in the market while, at the same time, determining the degree of majority consumer response to the vehicle type. Honda and Toyota appear to have recognized this opportunity.

Figure 2 is also intended to illustrate a proposed, somewhat arbitrary, definition of early buyers versus majority buyers. Below, we discuss in more detail the point at which we can draw the line between these two classes of buyers.

The evidence from the 1996 and 1997 Opinion Research Corporation (ORC) International surveys is consistent with the results shown in Figure 2. In Figure 3, we plot the category shares for all respondents from the 1996 and 1997 surveys that also asked consumers about willingness to pay to double fuel economy. Because the nominally exact $1,000 category (see Tables 4a and 4b in Section 3.4) is difficult to interpret within the cumulative framework and is a peculiar category relative to the other interval categories, we group the $1,000 category and the $1,001–2,000 category together into a $1,000–2,000 category. Figure 3 clearly shows that the share captured is largest within the $1,000–2,000 category, but as prices rise, share captured does not drop steadily (as in Figure 1 — see also discussion about Figure 8 in Section 4.2). Instead, when moving from the $2,001–3,500 category to the >$3,500 category, the share of respondents indicating they will purchase a vehicle doubling fuel economy almost doubles. The rational buyer model shown in Figures 1 and 8 appears to be inconsistent with this jump and instead implies a decline.

Ironically, however, the rational buyer model described in Section 4.2 does predict a similar percentage of buyers would purchase a vehicle that doubles fuel economy (25% vs. 20–21%) if the incremental cost were $3,500. Because the rational buyer model was constructed with an assumption of $1.50/gal, and the surveys were for a period when prices were approximately 20% lower, these >$3,500 results are quite comparable. However, the rational buyer model shown in Figure 8 in Section 4.2 predicts a share *improvement* of approximately

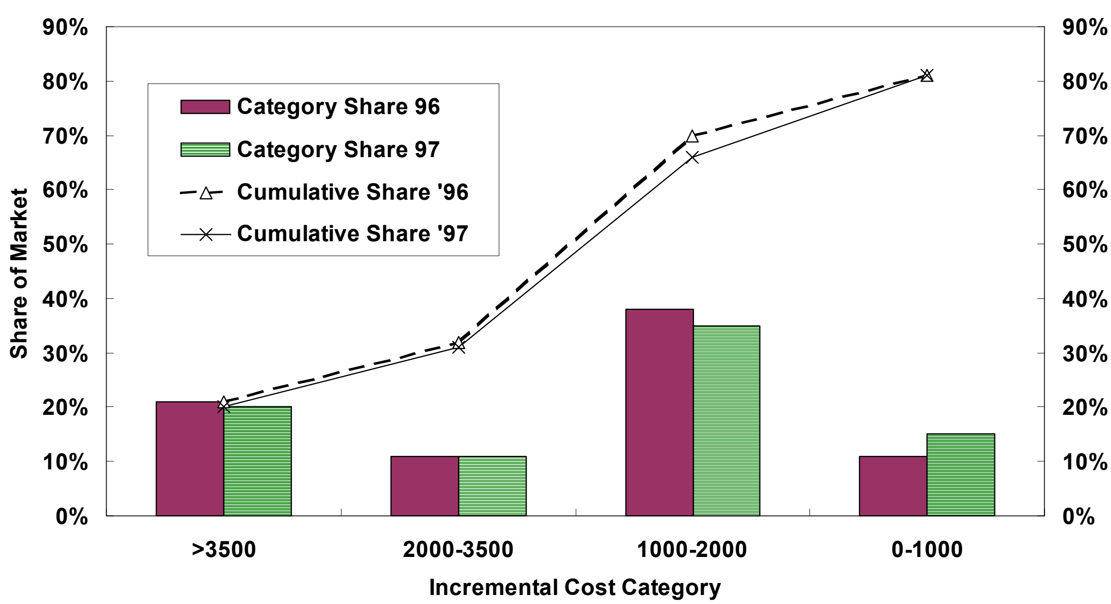

FIGURE 3 Willingness to Pay for Double Fuel Economy — Survey Results (ORC International 1996 and 1997)

35% for the \$3,500–2,001 interval (2001 assumed to be the midpoint of \$2,500 and \$1,500 intervals), while the 1996 and 1997 surveys predict a *decline* of share improvement to only 11%.

The pattern of share improvement for the survey cited in the Electric Power Research Institute (EPRI) report by Heim (1999), if shares are grouped similarly (though not identically), is about the same (Figure 4). The change made here was to select the cut point for the second interval at \$2,250 instead of \$2,001.

Although these observations of the share changes from three surveys are not definitive, they do indicate that more respondents than is "rational" indicate that they will purchase a vehicle with an incremental cost of \$3,500 or more. We attribute the additional number to a group of buyers appropriately called early adopters.

2.5 THE "TAKE-OFF" IN SHARE WHEN CROSSING THE 50% CUMULATIVE TOTAL

A consistent theme in the three survey results is a "take-off" in share within the \$2,250–1,000 incremental cost interval. Share gain from \$1,000 to 0 is much slower. Each of the cumulative share plots shows that the 50% cumulative share prediction occurs when moving into the \$2,250–1,000 incremental cost range. The share change per dollar drop within the interval traversed, when crossing the 50% cumulative share point, is consistently greater than that for any other cost interval.

The 1996 and 1997 surveys included "don't know" and "none" categories. Accordingly, the cumulative share predicted does not reach 100%. In contrast, the survey cited in the EPRI

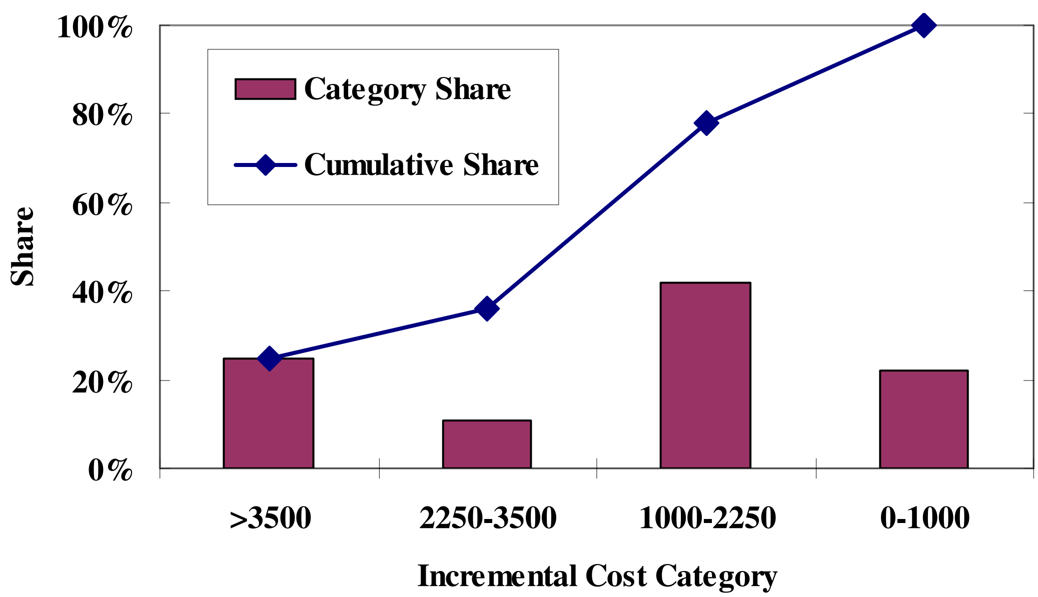

FIGURE 4 Willingness to Pay for Double Fuel Economy — Reconstituted Cumulative and Selected Incremental Cost Category Shares (Heim 1999)

study by Heim (1999) reaches 100% share. We speculate that the last adopters are, indeed, reluctant adopters. Unless they are given the opportunity to say so (by including a "nothing" willingness to pay category in the survey), this will not be revealed by the survey. We regard the predictions of the 1996 and 1997 surveys that some buyers will not pay for added fuel economy to be legitimate. This explains and justifies the note in the upper right hand corner of Figure 2.

The properties of the logit model are such that it is almost impossible for an advanced technology vehicle to reach 100% share so long as the base vehicle remains in the model. The processes involved at the end of the market introduction sequence, however, are not particularly important for this discussion, because the primary purpose is to properly characterize early buyers and perhaps early adopters.

2.6 THE POTENTIAL EFFECT OF EARLY ADOPTERS ON ELASTICITY ESTIMATES

In Figure 2, we provide an ad hoc estimate of the share of the market that would be obtained if all buyers follow the "rational buyer" model of Figure 1. Given the separate estimates of actual survey results versus a hypothetical rational buyers curve, the elasticity of response of share to a reduction in price can be computed for the assumed rational buyers (early buyers and majority buyers) and compared with elasticities estimated from reported actual responses. The computations are described below.

A fixed annual sales market m is assumed. The initial share before the tested \$1,000 price decline is S_t. The increased share after the \$1,000 price decline is S_b. Vehicle sales before the price decline are $S_t \times m$ and after are $S_b \times m$. The increase in sales is $(S_b - S_t) \times m$. For purposes of the estimates, the base vehicle is assumed to cost \$20,000. Computations of elasticity are done for \$1,000 cost intervals, from the introductory advanced-vehicle low-sales-volume price P_i (\$25,000) through the high-volume sales price P_e, which is set at \$20,000. The price at the top of each interval is P_t. The lower price at the bottom of the interval is P_b, which is \$1,000 less than P_t. The price evaluation interval $(P_t - P_b)$ is held constant at a \$1,000 decrease (-\$1,000). Elasticity is computed as:

$$\text{Elasticity} = [(S_b \times m - S_t \times m)/ (S_t \times m)]/ [-(P_t - P_b)/ P_t]$$

$$= [(S_b - S_t)/ S_t]/ [-1{,}000/P_t]$$

Although the interval for computation of the elasticity is a constant \$1,000 (this smoothes fluctuations due to discontinuities in the survey "curve"), elasticities are computed at each of the \$250 steps representing data in the curve of Figure 2. Seventeen values exist, each \$250 less than the last. However, to reiterate, the interval for the computation of each elasticity value represents the share change (and sales quantity change in a fixed size market) for a \$1,000 price decline from each starting price.

We plot the absolute values of elasticity in Figure 5. For the model with rational early buyers (i.e., the hypothetical buyers line in Figure 2), the theoretical assertion by Greene and Chin that the elasticity approaches a maximum (16 in this example) as share nears 0% and approaches (is closest to) 0 as share nears 100% is roughly confirmed. This pattern implies very rapid early response to price reduction after vehicle introduction. However, for the actual (all) survey respondents, the pattern of elasticities over the range of incremental cost values in the survey is considerably different. In stark contrast to the opposite result for the rational buyer share change assumptions, the estimated absolute value of price elasticity for the first $1,000 of price reduction is the lowest of any and is about one-fifth the absolute value of peak elasticity of about 10. This peak elasticity occurs *before* the 50% share is reached (between $3,000 and $2,500 — see Figure 2). (In stark contrast to the elasticity estimates resulting from the rational buyer share change assumptions shown in Figure 1, the estimated elasticity for the first $1,000 of price reduction is the lowest of any and is about one-fifth the peak elasticity of about 10. This peak elasticity occurs before the share reaches 50%.)

Greene and Chin chose an elasticity of about –8 to –10 at 50% share as the basis for constructing price slope coefficients. Interestingly, the elasticity computations based on the survey quoted by Heim also result in a similar elasticity estimate a bit earlier than when the 50% market share is reached. However, this is not a pure price-elasticity estimate, because a doubling of fuel economy is attached to the price differential.

This example and the overall exercise completed here illustrate that it is indeed possible that the imputed elasticity values at low market shares from stated-preference surveys are correct. Also, these surveys provide essentially the only information available for market-entry (extremely low share) conditions. Thus, until further experimentation is conducted to better

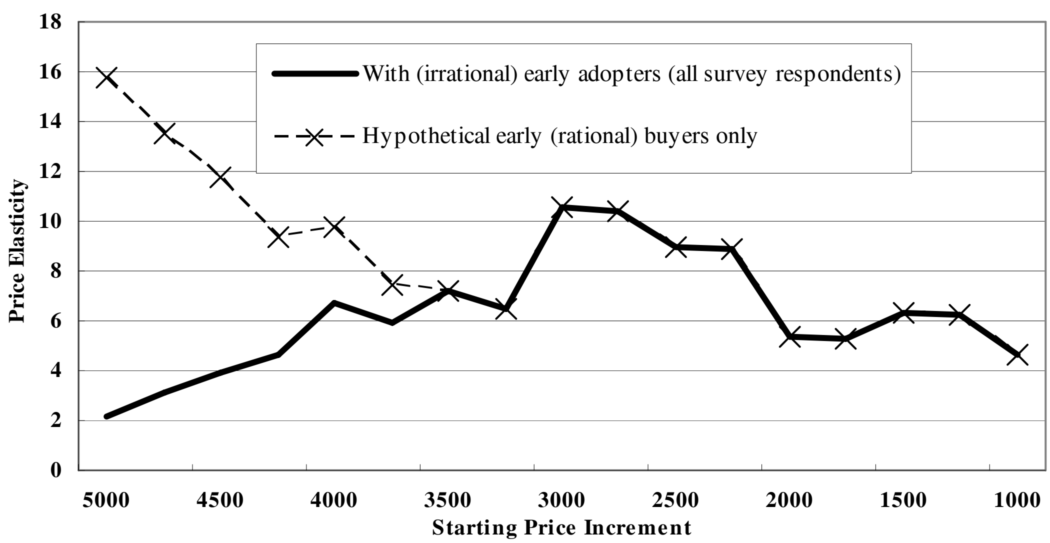

FIGURE 5 Estimated Fuel Economy Doubling Vehicle Price Elasticities for Full Sample vs. Assumed Early and Late Buyers (adapted from Heim 1999. Also see Figure 2.)

isolate early adopters and early buyers, our preference is to take the stated-preference survey results seriously and use them as the starting point for coefficients at initial market introduction.

In Section 2.8, we point out that the vehicle price coefficients estimated by Greene and Chin versus those of Tompkins et al. differ by a factor of 27. Figure 5 illustrates how this huge difference might come about. The model of consumer behavior that is imposed by the logit model requires that elasticity increases as share drops. However, our informed speculation (hypothesis) on the effect of the behavior of early adopters provides a plausible alternative pattern of behavior of elasticities, with elasticity of response actually dropping considerably as share drops. Thus, the alternative model of consumer behavior implies that the differences in traditional theoretical (dotted line, Figure 5) and actual (solid line, Figure 5) elasticity will diverge rapidly as share declines.

In Figure 5, at a value of incremental "2X" vehicle cost of $5,000, the difference between the hypothetical early buyer elasticity (16) and the actual respondent elasticity (2) is a factor of 8. That relationship applies at a share of about 20%. So, if the applicable share were much lower, then trend extrapolation would have the theoretical versus actual respondent elasticities diverge even further.

We suggest that theoretical statisticians consider the implications of implicitly imposing an incorrect functional form when estimating coefficients for a sample. In this case, if (when) the logit model's attributes are imposed on a group of survey respondents likely to select a small share of advanced technology vehicles, if the price elasticity coefficient is incorrectly estimated as if it applies at 50% share, then does the conceptual model incorrectly require that a very high price coefficient be estimated to simulate early introduction of advanced technology vehicles (ATVs)?

A final point concerning the sample data for the price versus share attainable is that the stated-preference studies and the revealed-preference studies do not even begin to address the same questions about consumer behavior. The stated-preference studies have collected data on the levels of increase in fuel efficiency and vehicle cost that are not experienced in the existing vehicle fleet. Generally, the stated-preference studies ask respondents if they would purchase vehicles multiple thousands of dollars more expensive, with percentage improvement of fuel economy in the tens of percents and above. Revealed-preference studies are, in effect, measuring responsiveness to changes in fuel economy of a few or several percent and costs of hundreds of dollars, not thousands. The two types of studies do not overlap with respect to the region of the price versus fuel economy trade-off that they examine. We have shown numerous reasons why results for such extremely different studies should vary. Until these explanations are evaluated, we suggest that models of consumer behavior attempt to take information from both types of study into account. We now make suggestions on how to do that.

2.7 THE PROBLEM OF OWN PRICE INELASTICITY (A LOW VEHICLE PRICE COEFFICIENT) AT LOW SHARE

The logit models developed to date for EIA and for the Office of Planning, Budget, and Analysis (OPBA) use a single coefficient for each attribute that is invariant relative to expected market share. Experiments with the behavior of the early 2003 OPBA model indicate that drastically different results are obtained when one compared models with a single (small) vehicle price coefficient from the stated-preference model of Tompkins et al., in comparison with the (large) revealed-preference coefficient developed by Greene and Chin. If the vehicle price coefficient used in a logit model is small, as in Tompkins et al., then it could be quite easy for an ATV or AFV to be predicted to enter the market, despite a high price.

On the other hand, a low vehicle-price coefficient greatly hinders the modeling from simulating an ATV or AFV rapidly gaining more share as the price drops as production volume and experience increase. One would expect that if a vehicle is able to enter the market, it could eventually expand share sharply if prices continue to decrease relative to the CV. However, a low vehicle-price coefficient was found to reduce the extent to which this is possible. In effect, adoption of a low vehicle-price coefficient could arbitrarily prevent a promising technology from ever being projected to win the market, even if it could sharply reduce prices below those of CVs. This restriction would be important in predictions for such technologies as HEVs and FCVs, if the long-term costs of these powertrains can be brought down sharply relative to CV powertrains over time.

The following example will illustrate the desired behavior of the model. Note that six-cylinder and eight-cylinder engines largely supplanted four-cylinder engines in the United States from about 1926 to 1935 (Naul 1978; Naul 1980). Many improvements in engines generally were made during this time, but it was always true that more cylinders cost more when choices were available. Yet, vehicles with higher-cost powertrains won the market. In that case, power appears to be the attribute that offset the purchase price differential for the model with more cylinders and drove the majority of manufacturers to shift to six- and eight-cylinder engines. A key consideration is that the model adopted must allow for the possibility that an AFV or ATV will capture significant market share, even though their initial cost may be higher than that of the CV.

Another consideration is that American automobile customers have always loved power, so their valuation of power relative to vehicle cost is potentially a very important attribute of the ultimate accuracy of the model to be adopted. Hermance (2003) also indicated that Toyota's research implies that American consumers value power more than they value fuel economy and explained that Toyota intends to take advantage of this preference in its marketing of hybrid electric vehicles.

As noted above, tests of the QM00 ("Quality Metrics" — supporting analysis — 2000) variant of the Advanced Vehicle Choice Model (AVCM), which used Tompkins et al.'s price coefficient, implied that rapid capture of the entire market would not be possible. However, the model tested with National Energy Modeling System (NEMS) -like vehicle price coefficients (Greene and Chin coefficients) did allow the complete capture of the market with a ±20%

variation in vehicle price. So, if late-buyer behavior is to be simulated properly, (1) Greene and Chin's arguments must accepted and (2) vehicle price coefficients of a magnitude comparable with theirs must be implemented for the majority of the population.

2.8 MARKET ENTRY VS. LATE BUYER BEHAVIOR — IMPLICATIONS OF GREENE AND CHIN'S VS. TOMPKINS ET AL.'S COEFFICIENTS

Greene and Chin state that the "the price coefficient serves as a scaling factor for all other variables in the model" and use this feature to deduce coefficients for attributes, given the vehicle price coefficient that they select, on the basis of revealed-preference studies. In Table 1, we list the variables and coefficients suggested in the Tompkins et al. and Greene and Chin studies. Also in Table 1, we present the estimate of the consumer's willingness to pay a higher vehicle price in exchange for the future benefits arising from "positive" (from the consumer's perspective — for example, a negative change in acceleration time is "positive" in this respect) changes in the attribute, which we have estimated by using methods explained in those two studies and adjusted to the same units when necessary.

Note that the vehicle price coefficient developed by Greene and Chin is 27 times as large as the one estimated in the stated-preference study by Tompkins et al. Yet, the estimated dollar *values* of a savings of one cent per mile in fuel cost vary "only" by a factor of eight. For an annual change of one dollar in maintenance cost, the value ratio is four; for a one-second change in 0–30-s acceleration time, the ratio is three; and for one-square-foot change in luggage space, the value is eight. The Tompkins et al. vs. Greene and Chin relative increase in valuation of fuel cost savings per mile is greater than the increase for acceleration. This information suggests that fuel efficiency is relatively more marketable to early adopters, which is consistent with the marketing strategies of Toyota and Honda with their first hybrids. Note, however, that the respondents to the Tompkins et al. survey did not have hybrid vehicles as a technology option.

Thus, despite the huge difference in vehicle price coefficients, the differences in attribute values are considerably smaller. Further, note that the attribute values estimated by Tompkins et al., in terms of implied dollar values, are consistently higher than those estimated by Greene and Chin by deductive logic and reference to revealed-preference studies for confirmation of "reasonableness."

Taking the comparative magnitudes of the coefficients of Tompkins et al. vs. Greene and Chin seriously, as evidence of the difference in influence between (1) early adopters and early buyers selecting from a wide range of technologies and (2) majority buyers selecting from a narrow range of technologies, we draw two major inferences:

1. Potential early adopters and/or early buyers indicated, through the national and California surveys, their willingness to "ignore" a high vehicle price if they liked other attributes of an AFV or ATV.

TABLE 1 Stated- and Revealed-Preference Coefficients with Recommended AVID Model Coefficients

Attributes	Tompkins Coefficient	Tompkins $Value	Greene Coefficient	Greene $Value	Early $Value	Early Coefficient	Late Coefficient	Comments
Vehicle price	-0.000048	-1	-0.00131	-1	N/A	-0.00002	-0.00131	The early coefficient is based on CEC-Morpace (2003) study — see text.
Fuel Cost Variables								
Fuel Cost (cents/mi)	-0.172000	$3,610	-0.622	$475	$1800	-0.0360	-0.0622	The Tompkins et al. (1998) $ value is judged too high — see text.
Fuel price Fuel economy (mpg)	NA NA	NA NA	NA NA	NA NA				AVCM uses fuel price and fuel economy as inputs, but estimates of consumer behavior are based on fuel cost per mile.
Refueling Variables								
Range	0.00165 (per mi)	$11,200 (80–400)	-207.2 (× 1/mi)	$1,580 (80–400)	$11,200 ($1,580)[a]	0.00068 (0.00010)	-207.2	Range value not estimated in the CEC-Morpace (2003) study. Different functional form used than in either study (1/x). See text.
Multi-fuel capability	0.120	$2,500			none	none	none	Hybrids expected to used gasoline, FCVs one fuel.
Home refueling of EVs			0.8806	$675		0.0135	0.884	Grid-connectable HEVs are still a possibility, provides credit.
Fuel availability	0.00394	$17.7 per % of gas to 25%	NA	$75 per % of gas	$17.7 per % of gas	0.000354	0.0983	Pertinent to hydrogen or methanol if used for FCV fuel.
Vehicle Attributes								
Top speed on level ground	0.00533	$112/mph	Not Investigated	Not Investigated	$112/mph	0.00244	0.0326	HEVs so far have lower top speeds than most vehicles. Top speed on grade significant in CEC-Morpace (2003) study. FCVs not limited?
0–30 mph time (s) 0–60 Greene and Chin 2000	-0.0756	$1,600/s	 -0.285	$651/s $217/s	 $1,000	 -0.02	 -0.285	Most evaluations use 0–60 instead of 0–30. We use 0–60. However, electric drive tends to give better 0–30 acceleration.

TABLE 1 (Cont.)

Attributes	Tompkins Coefficient	Tompkins $Value	Greene Coefficient	Greene $Value	Early $Value	Early Coefficient	Late Coefficient	Comments
Luggage space (per fraction of base trunk)	0.00683	$1,175	2.355	$150	$14,100 at 12 ft^3	0.282	2.355	Today's hybrids do not have a problem. Fuel cell storage is bulky, may take luggage space.
110-V supply (small appliances)	NA	See text	NA	See text	$4,500	0.090	Zero at > 50%	A separate ORC consumer survey was used. Both conventional and hybrids can provide this feature.
220-V supply (back up generator)	NA	See text	NA	See text	$4,500	0.090	Zero at > 35%	A separate ORC consumer survey was used. This capability more likely to be exclusive to high-voltage hybrids and FCVs.
Grid chargeable HEV	NA		NA			Enter as EV home refuel	Enter as EV home refuel	Only one coefficient and variable is developed to give grid-connectable hybrids credit for multi-fuel capability and home recharging. See above.
Urban emissions (% gasoline)	-0.00432 (in CA)	$96 per % drop				TBD	TBD	So far, hybrids are cleaner than most comparable conventional vehicles, and H_2 FCVs can have zero tailpipe emissions.
Maintenance Costs								
Annual maintenance cost	-0.00057	$12 per $1	-0.00397	$3 per $1	$24 per $1	-0.00048	-0.00786	Greene and Chin only consider direct costs, ignore value of lost time when getting maintenance done. We add time value.
EV/HEV Battery replacement (yes/no)	0.252	$5,300				Do not use	Do not use	Hybrids are now coming with long-life battery guarantees. Replacement should be folded into maintenance or lease cost.
EV Battery annual lease cost (replacement Greene)	-0.00061	$13 per $1	-0.00082 (one cost)	$0.63 per $1	$13 per $1	-0.00026	-0.00083	Note similarity to the maintenance cost coefficient from Tompkins et al. (1998). Far into the future, discounting lowers present cost relative to maintenance costs, which occur earlier.

TABLE 1 (Cont.)

Attributes	Tompkins Coefficient	Tompkins $Value	Greene Coefficient	Greene $Value	Early $Value	Early Coefficient	Late Coefficient	Comments
Familiarity, Choice								
Number of vehicles on the road	0.00081	$170 per 10,000				Do not use	Do not use	Difficult to develop a meaningful coefficient without better survey information. Might be negative for early adopters.
Make/model diversity			0.667	$2,350 (1–100%)		Consider	Consider	Coefficient not yet developed, but majority buyers may value this a lot. Early adopters may have a negative value for it.
Incentives/Privileges								
HOV lane access	See text		See text		4,500	0.090	0 at > 85%	A separate ORC consumer survey was used, and an estimate was developed with an assumed value of time for high-income early buyers. Only a small share of buyers can use it.

NA = not applicable.

TBD = to be determined.

[a] Coefficient for gasoline-capable vehicles.

2. The availability of the advanced-technology vehicles would prompt those groups of buyers to take a careful look at all vehicle attributes as a basis for making a decision and, as a collective group, assign more "points" (dollar value) to technological improvements than would the average consumer evaluating conventional technology.

So, the presence of these consumers challenges the vehicle manufacturer to produce a vehicle notably superior in key attributes to the average vehicle, and these buyers are willing to pay a higher price for the vehicle than the average consumer — if the manufacturer delivers. The flip side of this argument — applicable in particular to electric vehicles — is that the presence of such consumers will result in a considerable penalty for a manufacturer that tries to sell them a vehicle that has inferior attributes.

We therefore have a hypothesis that the relative values of the Greene and Chin and Tompkins et al. coefficients are, in reality, quite meaningful and alternatively represent the influence of a majority of consumers (late, majority buyers) and the influence of a relatively smaller group consisting of early adopters and early buyers. The emerging model seems logically reasonable. We know, for example, that Toyota has adopted a strategy with the first U.S. Prius of using selected, focused advertising to high-income, highly educated consumers in relatively elite magazines. More recently, as Toyota attempts to expand the market for the hybrid vehicle, it has actually begun to emphasize that hybridization can increase performance. Toyota's statements about a coming four-wheel-drive small SUV hybrid, the RX400, are that the engine displacement will not be changed, but the hybrid system will be an add-on that enhances both performance and fuel efficiency (Hermance 2003). The evolution of the 2000 Prius to the 2004 Prius also involved both an improvement in 0–60-mph and low-speed passing acceleration, as well as an increase in fuel economy.

The Tompkins et al. coefficients, relative to the Greene and Chin coefficients, imply that a manufacturer could gain a considerable advantage by attempting to be the first to capture a market niche of early buyers who are offered simultaneous improvements in both performance and fuel economy. Both fuel cost per mile and acceleration are assigned a considerably higher value in the Tompkins et al. estimates than in the Greene and Chin estimates.

3 IMPLICATIONS OF A DISTRIBUTION OF BUYER CHARACTERISTICS

3.1 BUYER LIFE CYCLE

Even if the majority of buyers use the same decision rules for vehicle choice, a set of buyers will make different decisions on the basis of their status. Important factors include stage in the life cycle, age (see Kavalec 1999), marital status, and number and ages of children in the household. However, such factors are not included in the model in question. The point is, however, that individuals change their vehicle-buying criteria during their lifetimes. So, even if everyone in a large population were the same, except for stage in the life cycle, there would still be a distribution of responses to vehicle attributes, because of variation among the population with respect to stage in the life cycle. Another key attribute that tends to change predictably over the life cycle is income, which tends to rise until the mid-50s.

Of course, individuals are not the same and vary in many important ways. One way in particular is location relative to job, shopping, and friends and acquaintances. Because of variation in these attributes, the amount of driving per year per vehicle varies considerably. Those who drive more would be expected to place a higher value on fuel savings. The net present value model allows us to formally estimate the consequences of this behavioral expectation.

A notable minority of contemporary consumers appears to place a high value on fuel economy. Hermance (2003) indicated that from 20% to 25% of buyers of passenger cars, minivans, pickup trucks, and small SUVs placed fuel economy in the "top box" of purchase criteria. Only for buyers of sporty subcompacts, large and mid-size SUVs, and luxury cars were these percentages smaller. For "non-sporty" subcompacts, the desire for good fuel economy was over 40%, and for hybrid buyers, it was over 80%.

3.2 DISCOUNT RATE AS A FUNCTION OF INCREMENTAL TECHNOLOGY COST

The fundamental trade-off that the model in question is designed to evaluate is fuel cost versus vehicle price. Many surveys could be cited to show that fuel cost is a very low priority for most buyers. Nevertheless, retrospective evaluation of results of a series of surveys conducted for Dr. Phil Patterson of the U.S. Department of Energy, by the ORC, implies that respondents do carefully and systematically evaluate the potential benefits of fuel cost savings. Table 2 presents summaries of results of three of these surveys conducted since 1998.

Each of the ORC surveys queries about 1000 households. Taken together, they provide information on what respondents are willing to pay for vehicles that increase fuel economy by 200%, 100%, 50%, and 10%. The survey asking about 200% and 100% increases in fuel economy was conducted in February 1998, the one on a 50% increase was conducted in August 1999, and the one inquiring about a 10% increase was administered on November 2, 2001 (ORC 1998, 1999, 2001). For comparison and reference, a net present value spreadsheet

TABLE 2 Survey Respondents' Valuation of 10–200% Increases in Fuel Economy

Parameter	February 19, 1998	February 19, 1998	August 5, 1999	November 2, 2001
Gasoline price ($/gal)	1.137	1.137	1.309	1.324
Base on-road MPG	19.4	19.4	19.2	19.85
Survey MPG gain (%)	200	100	50	10
Estimated advanced technology MPG	58.2	38.8	28.8	21.84
NPV savings at 15% ($)	2,700	2,000	1,600	420
NPV savings at 10% ($)	3,300	2,450	1,900	510
NPV savings at 5% ($)	4,100	3,100	2,400	640
NPV savings at 0% ($)	5,400	4,010	3,100	830
Survey value ($)	3,980	2,560	>2,000	>2,000
% Respondents	100	100	41	18
Expected value ($)	3,980	2,560	1,800[a]	390[a]

[a] See text for method of estimating expected value.

model previously developed by John Maples for Phil Patterson of DOE's Office of Planning, Budget and Analysis (OPBA) was used to estimate the value of fuel savings for a typical vehicle owner for a range of real interest rate assumptions, from 5% to 15%, assuming that respondents used the current price of gasoline at the date of the survey for their own estimates. The base in-use miles per gallon assumed to be used by the average respondent was the year's value for the light-duty fleet, as published by the Energy Information Administration in the Monthly Energy Review (EIA 2003, p. 17).

In the 1998 survey, respondents were allowed to specify an increase in vehicle price that they would be willing to pay in exchange for improved fuel economy within several ranges of dollar values. The average dollar value in the survey was then computed by the National Opinion Research Center, taking all responses into account. In the 1999 survey, respondents were asked if they would pay $2,000 or more for a 50% gain in fuel economy. Forty-one percent of respondents replied affirmatively. The difficulty with this survey is that no ranges were specified, so there is no way to know how much more than $2,000 the average respondent willing to pay $2,000 *or more* would have paid. If we assume that this amount would have been $3,000, and assign a value of $1,000 to the 59% unwilling to pay $2,000 or more, the expected value would be about $1,800, which would be consistent with a discount rate of 10–15% for an average vehicle buyer.

In the case of the last survey in 2001, 180 respondents indicated that they would be willing to pay something more than zero for a 10% gain in fuel economy. Among these respondents, the average value was $2,143. Given that 180 of about 1,000 respondents were willing to spend more than nothing, the implication is that 82% indicated they would pay nothing. By using this inference, the expected value for a 10% fuel economy gain was $386. This value implies a discount rate of over 15%.

The best match of the net present value savings for the average consumer, for the 200% fuel economy gain case, was obtained with a 5% discount rate, while for the 100% case, it was obtained with a 10% discount rate.

Taken together, these results imply that respondents are willing to pay less now per unit of fuel savings per mile as the percentage gain in fuel economy declines. Smaller gains in fuel economy seem to be evaluated with a higher discount rate than the larger ones. On the basis of these comparisons, it may be argued that consumers are likely to pay more careful attention to fuel savings when the amounts are large — and when they do pay careful attention, they tend to use a lower discount rate to evaluate the net present value of the fuel cost savings. In any case, the relative rankings of willingness to pay for fuel savings implies that rational consumers do, on average, use *approximate* (but systematically varying) net present value estimates in evaluating the worth of fuel savings.

3.3 DISCOUNT RATES, INCOME, AND THE PURCHASE AND UTILIZATION OF ENERGY-USING DURABLES

Hausman, in 1979, estimated the implied discount rate from revealed preferences for window air conditioner efficiency. Observations of relevance to this discussion include:

1. Individuals with higher-efficiency air conditioners use them more and

2. Income is an important variable in the distribution of discount rates in the population.

Hausman (1979) estimated the implied discount rates as a function of income. The sample was collected in 1976, soon after the oil price shock associated with the Arab Oil Embargo. Table 3 reports Hausman's estimated discount rates by income class in 1976 and income in 2002 scaled up on the basis of the urban consumer price index, which rose from 56.9 in 1976 to 177.9 in 2002. Hausman's language in the article makes it impossible to know the end points of the income classes. Note that inflation was much higher in 1976 than in 2002, so the real rate of discount implied below (nominal minus inflation) was actually very low. However, as Hausman points out, some of the effects should be related to marginal income tax rates, which are now much lower than those in 1976.

TABLE 3 Estimated Discount Rates as Applied to Window Air Conditioner Operations Savings, 1976 (Hausman)

2002 Scaled Income	1976 Income Class	Implied Discount Rate
$18,750	$6,000	89%
$31,250	$10,000	39%
$46,900	$15,000	27%
$78,200	$25,000	17%
$109,000	$35,000	8.9%
$156,000	$50,000	5.1%

Hausman's findings are consistent with one premise of this report (higher utilization rates are associated with purchases of more efficient equipment), but they also explicitly extend the premise to include the proposition that discount rates applied by higher-income purchasers are lower. These two effects should synergistically increase the likelihood that more-efficient vehicles will be purchased as income rises. As the price of a new technology falls over time as a result of economies of scale and learning effects, early year adopters of more fuel-efficient technologies should be higher-income buyers.

Note that this observation is intuitively consistent with the fact that purchasers of more-expensive and more fuel-efficient technology (see Section 3.2) appear to apply lower discount rates to their purchase decision. Logically, then, only higher-income respondents would be likely to assert that they would purchase the most costly of the technologies.

3.4 PREFERENCES FOR FUEL EFFICIENCY VS. ANNUAL DRIVING

On October 17, 1996, and October 24, 1997, two surveys were conducted by the ORC for DOE's OTT, asking respondents to state their willingness to pay for a doubling of fuel economy. The 1997 survey told respondents that the average spending per year on gasoline was about $600, but the 1996 survey did not. Two categories of respondents for which the data were compiled were male and female respondents. Before we examine the results, we note that "between the ages of 20 though 54 years, men's driving is in the range of 17,000 to 18,000 annual miles; women's driving during these same ages averages 11,000 miles per year" (U.S. Department of Transportation 1997). Although this statistic does not prove that vehicles driven primarily by men are driven more miles per year than vehicles driven primarily by women, it strongly suggests that this is true. Thus, vehicles purchased by men for their primary use are likely to be considerably more intensively used than vehicles purchased by females primarily for their own use. The implication is that men should be willing to pay more for fuel efficiency than women, and the surveys clearly imply this willingness.

TABLE 4a Male vs. Female Willingness to Pay for Doubling Fuel Economy — Not Adjusted for Differences in "Don't Know" Answers

	Percent Willing to Pay			Percent Willing to Pay		
$ for 2× MPG	**Male (1996)**	**Female (1996)**	**Difference (1996)**	**Male (1997)**	**Female (1997)**	**Difference (1997)**
None	10	10	0	9	14	-5
<$1,000	7	14	-7	15	16	-1
$1,000	14	15	-1	18	11	7
$1,001–2,000	24	21	3	22	18	4
$2,001–3,500	13	9	4	12	10	2
>$3,500	27	16	11	21	20	1
Don't know	5	14	-9	4	11	-7
Sum	100.0	99.0		101.0	100.0	

TABLE 4b Male vs. Female Willingness to Pay for Doubling Fuel Economy — Adjusted for Differences in "Don't Know" Answers

	Percent Willing to Pay			Percent Willing to Pay		
$ for 2× MPG	Male (1996)	Female (1996)	Difference (1996)	Male (1997)	Female (1997)	Difference (1997)
None	10	11.0	-1.0	9	15.1	-6.1
<$1,000	7	15.5	-8.5	15	17.3	-2.3
$1,000	14	16.6	-2.6	18	11.9	6.1
$1,001–2,000	24	23.2	0.8	22	19.4	2.6
$2,001–3,500	13	9.9	3.1	12	10.8	1.2
>$3,500	27	17.7	9.3	21	21.6	-0.6
Don't know	5	5	0	4	4	0
Sum	100.0	98.9		101.0	100.0	

Because the number of female respondents who replied "don't know" was notably higher than the number of males, a second comparison was made, in which the proportions were adjusted as if those who do know represent the same proportion for both males and females. The implications remain the same. Consistent with the expectation that men's primary vehicles are driven more miles, men respond that they will pay more for doubling fuel economy than will women.

An interesting nuance suggests that the survey respondents deliberate more carefully than some may expect. In the 1997 survey, respondents were told that they spend $600 per year on fuel. Thus, respondents in the second survey were given a number that may have been inconsistent with their experience. The difference in results relative to the 1996 survey where no "appropriate" annual spending value was suggested indicates that respondents were inclined to take the $600-per-year number in the 1997 survey into consideration in the manner of a test question. In light of the $600 annual value, the second group probably was more likely to evaluate the fuel savings on the basis of the survey's assertion (rather than their own experience) than the first group. Men should have decreased their estimate of fuel use, and women should have increased it. Differences should have decreased. In fact, the sum of absolute differences in responses declined in the second survey. Further, the evidence that men are far more likely to pay more than $3,500 for a doubling of fuel economy than women disappeared.

The first survey response — which was given without a prior statement about the amount of dollars spent on fuel to use to compute the answer to the question — may have been the more informative. Certainly, these results are consistent with the early buying patterns for the Prius, which was dominated by male purchasers, according to Heraud (2001) (63% men for the Prius, 44% for the Camry, and 45% for the Corolla). Hermance (2003), two years later, indicated that the purchasing demographics for the Prius changed over time, from an early 72% male purchasers to a present 48% share, which is now very similar to the pattern for the Camry and Corolla.

Perhaps men were interested in the advanced technology features of the Prius when it was introduced. However, it is also possible that the higher early proportion of male purchasers bought the Prius because men drive their vehicles more miles per year. More likely, both attributes of male consumers had an effect on early Prius sales.

Another consideration related to the 1997 DOT survey's finding that females drive 7,000 fewer miles per year than males is the likelihood that men or women know the number of miles individual vehicles are driven in the household. Because males clearly drive more on average, and if the male is likely to have more responsibility for driving for vehicle maintenance and refueling than the female in households headed by both a male and female, then the male should be more familiar with vehicle records and totals of miles driven. If so, then males should be less likely to respond "don't know" than females. This was the case in the two surveys discussed in this section: females did, in fact, respond "don't know" almost three times more frequently than males.

One test that is suggested from the information on the early high proportion of male buyers for the first U.S. Prius model is to examine whether males are more likely than females to indicate that they wish to gain attention or be a pioneer (as noted earlier, 33% of persons surveyed for the Graham et al. (2001) study indicated "attention/pioneer" to be an important reason to buy a hybrid). Another way of looking at this parameter is to determine if self-identified "early adopters" are more likely to be male.

Hermance (2003) described the recent sequence of buyer demographics as moving to the "early majority" buyer profile, in contrast to the early adopter. He indicated that these buyers are well informed, do lots of research, are risk-averse, and want a well-proven and tested product. In our opinion, this group is within our early buyer group — probably high income, well educated, and driving more miles per year than average. However, the prior statements are hypotheses that deserve testing rather than a position that can be defended with survey findings.

4 TRADE-OFFS: FUEL EFFICIENCY, INCREMENTAL COST, AND PURCHASER INCOME

4.1 INCOME OF EARLY BUYERS OF FUEL EFFICIENCY

With respect to the higher-than-normal valuation of fuel efficiency, key causal factors for such buyers are argued here to be income (see Table 3 and related discussion) and amount of driving. In fact, these two factors are correlated, as Figure 6 illustrates (Department of Transportation 2004). The figure shows that as household income rises through about $50,000 per year, the annual miles driven per vehicle rises steadily, then plateaus. Of course, the amount of driving per household may still rise. If so, however, this rise would be the result of a household purchasing more vehicles rather than driving vehicles more miles.

The effect of household income was, in fact, tested in the CEC-Morpace stated-preference survey. In Table 5, we include the coefficients and attribute values from the "statewide models" of the survey. Morpace and the CEC also developed urban-area-specific coefficients, but we ignore those results here, because the intended purpose is a national model.

Analysts conducting the CEC-Morpace study tested for differences in coefficient values by household income. Consistent with the implications shown in Figure 6, CEC-Morpace analysts found that the most logical break point for separate coefficient estimates was $50,000 of household income. They demonstrated that, for one- and two-vehicle households, the price coefficient of households with $50,000 or more of income was less than half of that for households with incomes of less than $50,000. This break was not demonstrated for three-vehicle households, but it was estimated to be significant for one- and two-vehicle households, representing a significant majority of new vehicle buyers. The single price coefficient for all three-vehicle households was closer to the price coefficients of households with incomes of

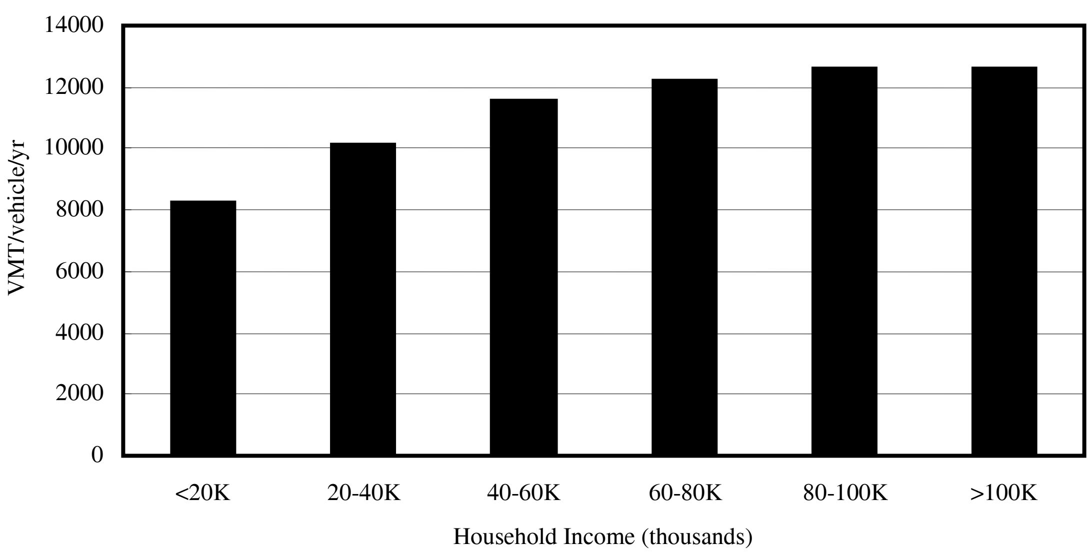

FIGURE 6 VMT Driven per Vehicle per Year as a Function of Household Income

TABLE 5 CEC-Morpace 2002 Study Coefficients — Statewide Segment Models

		1 Vehicle Segment		2 Vehicle Segment		3+ Vehicle Segment	
Vehicle Attribute	Unit	Coefficient	Implied Value ($)	Coefficient	Implied Value ($)	Coefficient	Implied Value ($)
Purchase cost if HH income <$50K ($)	2002 $	-0.0000349	-1.0	-0.0000664	-1.0	-0.0000204	-1.0
Purchase cost if HH income >$50K ($)	2002 $	-0.0000137	-1.0	-0.0000259	-1.0	-0.0000204	-1.0
Maintenance cost if HH inc. < $50K ($)	2002 $/($/yr)	-0.0014700	42.1	-0.0016800	25.3	-0.0011700	57.4
Maintenance cost if HH inc. > $50K ($)	2002 $/($/yr)	-0.0010900	79.6	-0.0010500	40.5	-0.0007400	36.3
Fuel cost if HH income < $50K ($)	2002 $/($/yr)	-0.0002129	6.1	-0.0001351	2.0	-0.0000502	2.5
Fuel cost if HH income > $50K ($)	2002 $/($/yr)	-0.0002129	15.5	-0.0001351	5.2	-0.0000502	2.5
0–60 mph if HH income < $50K (s)	s	-0.0440000	1,260	-0.0560000	843	-0.0570000	2,790
0–60 mph if HH income > $50K (s)	s	-0.0440000	3,210	-0.0560000	2,160	-0.0570000	2,790
Gradeability if HH inc. < $50K (mph)	mph	0.0110000	-315	0.0110000	-166	0.0030000	-147
Gradeability if HH inc. > $50K (mph)	mph	0.0110000	-803	0.0110000	-425	0.0030000	-147
Diamond lane if HH inc. < $50K (yes)	yes = 1	0.1340000	-3,840	0.0000000	0.0	0.0000000	0.0
Diamond lane if HH inc. > $50K (yes)	yes = 1	0.1340000	-9,781	0.0000000	0.0	0.0000000	0.0

$50,000 or more in the one- and two- vehicle households than to the price coefficients of those with less than $50,000 of income. We speculate that the reason is that a disproportionate share of households with three or more vehicles is in the $50,000-and-above income category.

Thanks to the CEC-Morpace tests, we have evidence that a higher income does lead to a lower sensitivity to price. Because new car buyers are, on average, from higher-income households than used car buyers, a new vehicle purchase model should logically have lower price coefficients than a model capturing preferences for the general population. Greene and Chin do not develop or discuss this hypothesis or relationship. No reference to used vehicles can be found in their discussion. However, the one reference cited by Greene and Chin that is clearly identified as a study of new vehicles provides very high elasticity estimates, contrary to this hypothesis.

The CEC-Morpace analysts have tested other coefficients for effects of household income. In addition to reporting separate price coefficients for incomes above and below $50,000, they also present separate price coefficients for maintenance costs. By not presenting separate estimates by household income for fuel cost, acceleration, gradeability, and access to diamond lanes (Table 5), the CEC-Morpace analysts imply that there is no statistical basis for differences in the coefficients as a function of household income. This point is important, because if either the price coefficients or the attribute coefficients have a different value above and below $50,000 of household income, the implied value of the attribute varies as a function of income. In this case, the result is that the CEC-Morpace study coefficients imply that higher-income households actually place a higher value on fuel efficiency than do lower-income households, which is consistent with the 1979 findings of Hausman with respect to air conditioners, as discussed previously.

This is an encouraging finding, implying that new car buyers actually value fuel savings more highly than do used car buyers. However, we need to be cautious about this interpretation. To be consistent with the arguments that the stated-preference surveys involving new technologies are influenced by the preferences of early buyers, we may have information heavily influenced by a minority of buyers. Because the stated-preference surveys are intended to bring out information about the preferences of all buyers of fuel efficiency, it may not be reasonable to extend the minority property of higher preference for fuel efficiency at high income to the majority buyers. At present, we do not adjust majority new car buyer coefficients upward from the Greene and Chin values.

The question arises — who are the people causing the apparently too high valuations of fuel efficiency in stated-preference studies and why are they doing it? We speculate that, in part, they are buyers in high-income households who drive a lot. This hypothesis could have been tested in prior stated-preference surveys by (1) separating the respondents who selected highly fuel-efficient vehicles from those who did not and (2) providing a test of differences from the remainder of respondents. Unfortunately, this analysis has not been done, and so we must speculate that our hypothesis of logical rational behavior is correct.

The discussion in this section has focused on what we term early buyers. We have attempted to distinguish between early buyers and early adopters. It is quite possible that early adopters and not early buyers heavily influence the results of the stated-preference study. To explore this hypothesis, we first develop a logical model of buyer behavior based only on income, incremental vehicle cost, and fuel economy gain. We then examine the implications for evolution of market share with time, as the market expands and as incremental costs of fuel efficiency decline with sales volume and production experience. We then consider the implications of the existence of early adopters and the role that they could play in a successful sequence from introductory vehicle technology to mass-market vehicle technology. Finally, we examine the potential implications of the existence of early adopters for survey results at low market shares.

4.2 MARKET SHARE IF BASED ONLY ON INCOME, FUEL SAVINGS, AND DECLINING INCREMENTAL COST

Absent time or funds to reexamine prior stated-preference studies, we use the Greene and Chin approach of deductive logic based on net present value thinking. First, we note that there is a distribution of annual vehicle miles traveled (VMT) per vehicle owned by potential buyers. We used the analysis option on the Oak Ridge National Laboratory 2001 National Household Travel Survey web site[2] to develop information about this distribution. We did a cross-tabulation of miles driven in the last 12 months versus self-reported annual vehicle miles of travel per vehicle.

[2] U.S. Department of Transportation, 2004, “2001 National Household Travel Survey ‘Create a Table’” web site [URL http://nhts.ornl.gov/2001/Login.do?state=checkLogin].

From zero to 30,000 miles driven in the last 12 months, the program gave us results for 5,000-mile increments. The next two increments were from 30,000–40,000 miles and 40,000 miles and above. For every class, the average reported annual VMT per vehicle fell within the interval, indicating a very high correlation. Taking the counts by interval, we developed an approximate smooth decline in percent in each 5,000-mile increment from 30,000 miles to 60,000 miles, in order to have a reasonable description of the frequency distribution of annual miles driven per vehicle in the United States, from 0–60,000 miles per year (Table 6).

The average U.S. light-duty vehicle has a lifetime in miles driven of about 140,000 miles. Of course, many vehicles last more miles, and many last fewer miles. The number of years of life is another issue. The NPV model used here to compute savings resulting from a doubling of fuel economy includes a maximum of 11 years of life. For net present value analysis, the fuel savings for years 12 and beyond makes very little difference. To be consistent (and to be able to use the model without modification), we assumed a maximum of 11 years of life. As annual miles driven rises, an assumption of 11 years of vehicle life becomes untenable. When the number of annual miles driven times 11 exceeded 140,000 miles, we assumed that the number of years of life of the vehicle must be reduced. Those who drive a vehicle many miles per year are likely to be able to obtain more miles of vehicle life because they put miles on the vehicle before causes of vehicle failure due to age become powerful factors. We assumed a maximum amount of miles of life to be in the 210,000–225,000 range. After the 10,000–15,000-mile annual VMT bracket, years of life were monotonically dropped (Table 6).

The NPV model was run for the years assumed, for a gain from 20 mpg to 40 mpg, with a real interest rate of 10% and a real gasoline price of $1.50/gal. Note that we use only one discount rate in the development of this model. By the logic presented earlier, the early buyers in

TABLE 6 Assumed Patterns of Vehicle Use in the United States and Value of Fuel Saved via Doubling of Fuel Economy

Annual Miles (10^3)	Share (%)	Cumulative Share (%)	Lifetime Miles	Lifetime Years	NPV Savings ($)
<5	34.0	34.0	30,926	11.0	709
5–10	15.9	49.9	87,223	11.0	2,000
10–15	24.3	74.2	126,543	11.0	2,901
15–20	11.4	85.6	162,032	10.0	3,837
20–25	6.7	92.3	187,386	9.0	4,598
25–30	2.7	95.0	209,508	8.0	5,328
30–35	1.9	96.9	210,000	7.0	5,555
35–40	1.2	98.1	210,000	6.0	5,784
40–45	0.8	98.9	225,000	5.0	6,456
45–50	0.5	99.4	225,000	4.5	6,644
50–55	0.3	99.7	220,000	4.0	6,576
55–60	0.2	99.9	210,000	3.5	6,554

the market would be expected to be higher income and use a lower discount rate in their evaluations than majority buyers. The effect of this omission is discussed later.

The estimated fuel savings from the NPV model was for a single, default total mileage that was different from any single value of lifetime miles shown in Table 6. Therefore, the ratio of the generally varying total lifetime mileage from each row in Table 6, divided by the constant mileage used in the NPV program, was multiplied by the NPV savings estimate of the program to develop the NPV savings estimate in the last column of Table 6. This value could be regarded as a very rough estimate of the effects of implementing the hybrid powertrain technology of the 2004 Prius hybrid (and other fuel economy improving factors) in an average U.S. vehicle. The savings versus annual miles of driving from Table 6 are plotted in Figure 7. In the following discussion, we assume that the NPV of savings from doubling fuel economy would support the incremental price.

The Prius cost is approximately $20,000. If the previously cited estimate of an 18% increase in purchase price were to apply, then the incremental vehicle cost would be $3,600. However, an average new vehicle in the United States, including trucks and larger cars, probably sells closer to $25,000. If so, then the incremental cost for a doubling of fuel economy would be $900 more, or about $4,500. According to the estimates in Table 6, if the trade-off between vehicle price and fuel economy were the only concern to the buyer, this would mean that the 2004 Toyota Prius-type technology package could eventually gain from 8% to 14% share of the

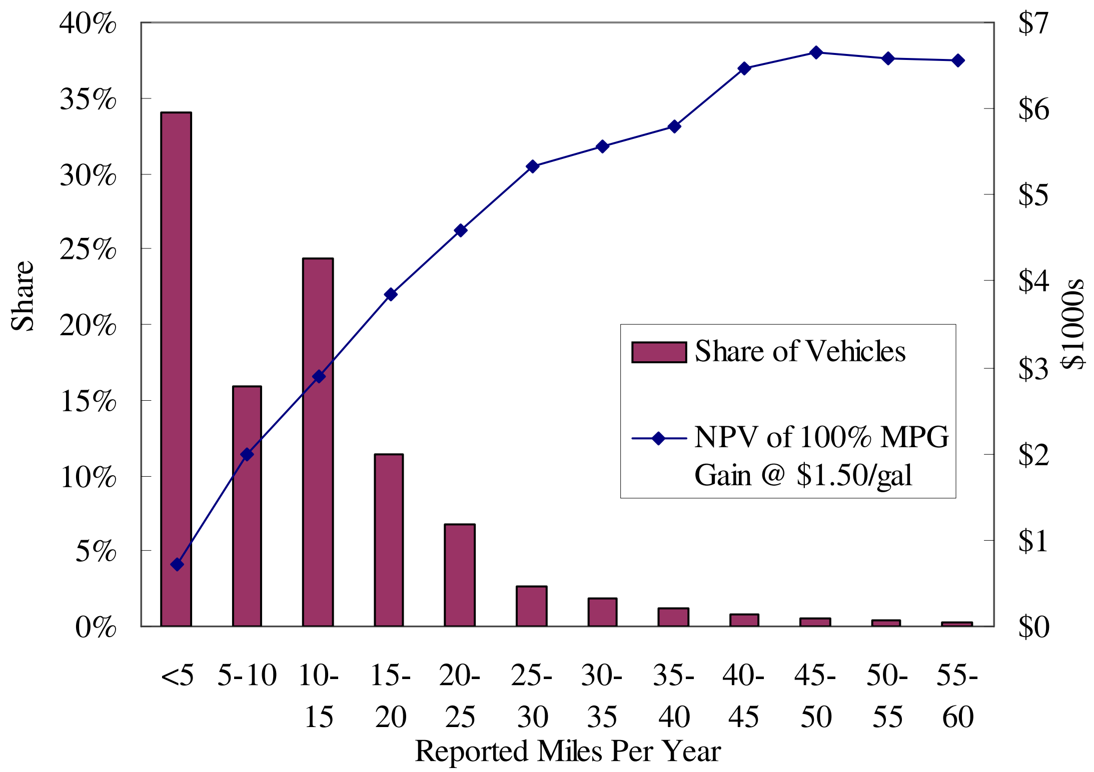

FIGURE 7 VMT Driven per Vehicle per Year vs. Estimated Fuel Savings (see text for details of estimates)

U.S. market, with present driving patterns and if real fuel prices remained at current levels. However, as noted, we may have used too high a discount rate for this part of the market and therefore may have underestimated the probable share.

For our purposes, we are also interested in the implied behavior of this logical model of market penetration in terms of price elasticity. We now can estimate the change in share as incremental price drops. Hypothetically, according to Table 6, if the incremental price of an average new vehicle in the United States is over $7500 for this package of technology for doubling fuel economy, there will be no sales. If the incremental price can be dropped to $500, it might be possible to capture all of the market. We constructed a hypothetical set of steps to reduce the price of the technology package from $7,500 to $500 and compared the share gain to the percentage price reduction to obtain an estimate of elasticity of response of the market share to price reduction. Because percent decline in price multiplied by elasticity must be a positive number, elasticity is a negative number. However, the absolute value of elasticity is plotted in Figure 8.

Figure 8 plots change in share as a function of change in incremental cost. Share is seen to rise sharply as price declines. As shown in Table 6, it is evident that as the price difference drops, there comes a point at which large (and presumably rapid) expansions of the market are possible.

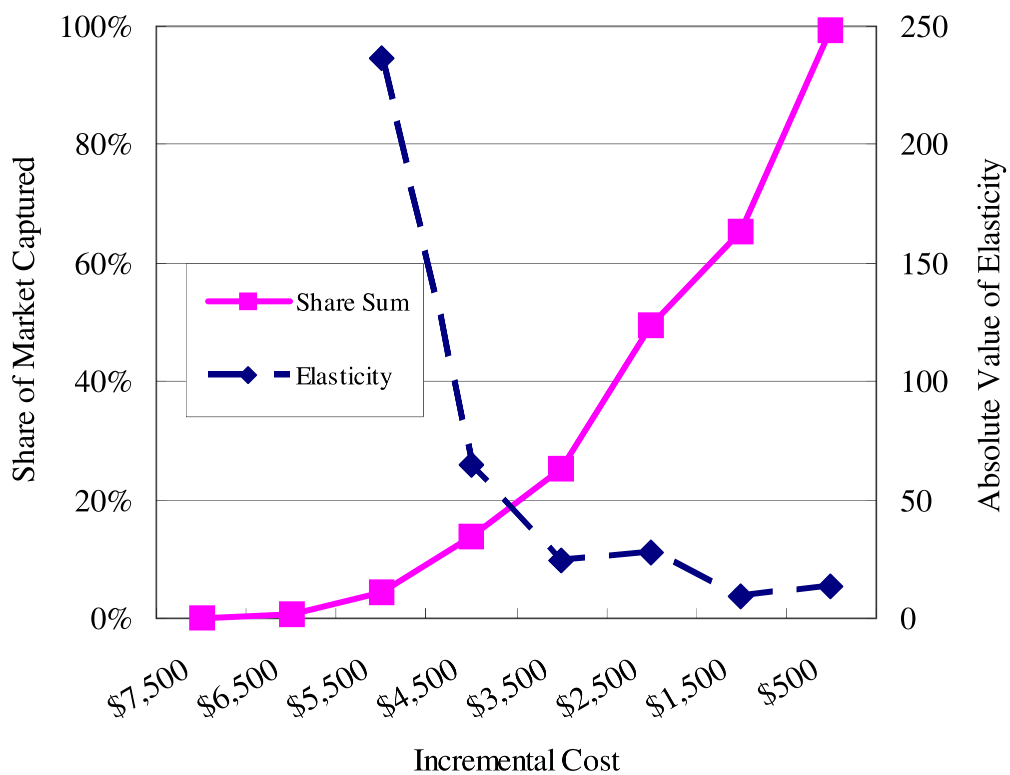

FIGURE 8 Incremental Costs to Double Fuel Economy vs. Market Share Attained and Elasticity of Response at Each Price Reduction Step

This "logical model" of change of share as a function of price and annual miles driven provides a pattern of elasticity somewhat like the theoretical pattern produced by the standard logit model, as shown in Figure 1. The elasticity plot in Figure 8 is, however, consistent in that it starts out very high and drops dramatically as the incremental price of a hypothetical hybrid vehicle drops. Therefore, if straightforward net present value of fuel savings as a function of miles driven are the key cause of initial interest in the hypothetical advanced hybrid technology capable of doubling fuel economy, then the logit model, unmodified, should be adequate.

However, we note that the shape of the curve in Figure 8 (buyer model curve) in the initial introduction (high price) region is inconsistent with the shape shown in Figure 2. In effect, the survey reported by Heim (1999) indicates a much higher percentage of buyers at high incremental prices than does this rational buyer model based on discounted real fuel savings.

If the survey responses (Figures 2–4) indicate genuine probability that consumers will purchase an advanced hybrid technology at high incremental cost, then the simple rational buyer model in Figure 8 is probably inadequate to describe market shares attained at high incremental prices for a new technology that can double fuel economy. We argued in Section 2.6 that it is legitimate to identify the difference between the survey response and the rational buyer model described in this section as due to the category of buyers appropriately called early adopters.

5 COEFFICIENT SUGGESTIONS

In Table 1, we have bundled attributes according to what are considered logical groupings. We will discuss the coefficients and make recommendations, in the context of those groupings. Suggested "starting point" coefficients for a generic one-vehicle-class model are listed in Table 1. Note that the thought process related to desirable coefficients is forward-looking, in that it considers vehicle technology attributes for advanced hybrid electric and fuel cell vehicles.

In the case of the Tompkins et al. and Greene and Chin efforts at constructing coefficients, the types of vehicles and fuels for which coefficients were needed were different from the types needed for the next decade. In particular, the type of hybrid vehicle produced and marketed by Toyota and Honda were simply not anticipated in the early 1990s when the California studies, which dictated the form of the Tompkins et al. studies were developed. Similarly, the coefficients developed by Greene and Chin for the EIA National Energy Modeling System attempted to incorporate the types of vehicles for which regulations were incorporated in AMFA and EPACT.

Unlike Tompkins et al., Greene and Chin were able to develop estimates of relationships unconstrained by a self-imposed requirement to allow joint estimation with prior stated-preference studies. This approach allowed us to construct different functional forms and use some new surveys dedicated to particular consumer preferences. Ironically, although Greene and Chin dismissed the Tompkins et al. coefficients and study, they did not hesitate to use stated preference when they had some degree of control over the questions asked in the stated-preference survey. Regardless, Greene and Chin's work is more credible as a probable description of the average consumer than is the Tompkins et al. survey. Tompkins et al. makes sense only if interpreted as providing information about the influence of early adopters and/or early buyers when AFVs or ATVs are first entering the market.

Like Greene and Chin, in this assignment for a U.S. Department of Energy sponsor, we too have the freedom to think about proper coefficient values without constraints. Drawing upon research about technical attributes of HEVs and FCVs, we can provide a revised list of recommended coefficients, as well as recommend changes of coefficients for variables that should be retained in the vehicle choice models.

A fundamental suggestion is that the model be programmed to cause the coefficients for the early adopter/buyer move toward the value of the late buyer coefficients moderately rapidly and, ultimately, be held constant at a value close to that of the late buyer coefficient. Although early adopters may strongly influence coefficients at very small shares early in the introduction process, in the longer term, early buyers — who are actually quite similar to majority buyers — will dominate the choices of advanced technology vehicles by the early group. These buyers will be different from majority buyers in terms of circumstance, but not in purchase evaluation strategy. Because they have unusual attributes, early buyers/adopters of highly fuel efficient vehicles represent a minority of the market. The recommendations for coefficients discussed in the following sections attempt to take these realities into account.

In the case of the hybrid, if the long-run incremental price of a hybrid powertrain capable of doubling fuel economy must be greater than $3,000 (very likely), then the percentage of the market willing to pay enough to allow this amount should be the target market for the hybrid powertrain producer. According to Figures 3 and 4, this would be a bit over 20% of the market. Table 6 implies that about 25% of rational buyers would pay such an amount, and any early adopters who drive fewer miles (but would purchase a hybrid vehicle for other reasons) would come from the remaining 75% of the population and increase the total share of buyers. If, at introduction, because of higher costs at low volume the producer considering the introduction of hybrid powertrains would have to be able to sell early versions for $5,500 above the price of a comparable conventional vehicle, then the implied potential market share of rational buyers (as illustrated in Table 6) would be about 5%. This share would leave a slightly larger pool of non-rational buyers from which to draw, at 95% of the population, so the proportion of individuals who would fit into our definition of early adopters would increase somewhat.

5.1 VEHICLE PRICE

Hereafter, we term the combined "early adopter" and "early buyers" the early group. We recommend that the initial vehicle price coefficients for the early group be set at approximately the value obtained in the CEC-Morpace study for households with incomes greater than $50,000. After an initial setting of coefficients, the model should be set up to cause the coefficients of the early group to converge toward the majority group, with the coefficients of the early group changing rapidly as important, but fleeting, effects of early adopters fade.

In light of the "take-off" phenomenon (in which there is rapid adoption of new technology taking place as the 50% of ultimately attainable share is crossed), a rough rule of thumb for the model would be to have stabilized early group coefficients after about 50% *of the ultimate market* is served. The early group should always have a stronger preference for fuel efficiency than the majority group and a stronger preference for fuel savings relative to performance (see appendix and Section 2.8). The ratios of recommended elasticity at the 1% market share level and 50%+ level are approximately equal to the ratio of Greene and Chin's coefficients (-0.00089 to -0.00131) and the coefficients for households with more than $50,000 of income from the CEC-Morpace study (-0.000026 to -0.000014). The pattern of change of market share versus incremental advanced vehicle cost elasticities from 1% to 100% of the market should be shaped (very) roughly like that of all respondents to the survey (the "with early adopters" case) quoted in Heim et al. (Figure 5). We reiterate that, with respect to initial elasticities at low market share, this pattern is opposite to the theoretically "correct" one noted by Greene and Chin.

5.2 FUEL COST

The Tompkins et al. and Greene and Chin coefficient set involves developing a coefficient for fuel cost per mile. In the conceptual models used, fuel cost is the key attribute, whether it is changed by fuel price or vehicle fuel economy. The QM00 version of the Advanced Vehicle Choice Model (AVCM) and subsequent versions had a separate entry for fuel price and fuel economy. Although this feature should be retained for inputs into the future model, we recommend that a coefficient only for fuel cost per mile be implemented in the model.

Greene and Chin construct a fuel cost coefficient by using deductive logic and discounting future cost savings to a present value. They estimate that a savings in fuel cost of one cent per mile should be worth $475 for a small car. The logic that they apply implies that an early buyer could not possibly be willing to pay more for fuel savings than the dollars saved per vehicle for an average amount of vehicle travel per year. The Tompkins et al. results are inconsistent with this assumption and indicate that early buyers would pay far more for fuel savings. Our explanations for this phenomenon are that (1) some early adopters should view fuel economy improvements favorably when the differential is so large that it is a noteworthy distinction of the vehicle technology; (2) early buyers drive their vehicles a lot of miles per year, because most of them have high income; and (3) early high-income buyers also apply a lower discount rate to future fuel savings. Further, we argue that large savings at high cost are likely to garner a very careful evaluation of fuel savings.

With respect to early buyers, we postulate that these consumers are willing to pay more because they are among a small group of consumers who drive vehicles far more than average. A separate key segment of the population is the early adopters, who are altruistic and have in mind the secondary benefit of improved environment and energy security. Toyota's and Honda's advertising for the Insight and earlier Prius emphasized the altruistic environmental benefits of their hybrids. Also, as noted above, it is likely that an important subset of early adopters liked to brag about their purchases and placed a high value on owning the vehicle with the greatest fuel economy among their friends and peers.

Suppose we assume that early buyers (1) use a low discount rate and evaluate savings over a short life of the vehicle and (2) drive many more miles per year than the average driver. We assume about 50,000 miles are driven per year for a four-year period for the first 1% of the market (bottom three rows of Table 6). This assumption gives a present value of a one-cent-per-mile fuel savings of about $1,800, which is about one-half of the value Tompkins et al. estimated. Thus, we recommend an "early buyer" fuel efficiency coefficient at 1% share that will result in a dollar value of about one-half of the value Tompkins et al. obtained. The coefficient should then rise nearly to the level of Greene and Chin's coefficient, which is approximately 50% market share, and then held constant through 100% of the market.

5.3 REFUELING

Range, multi-fuel capability, and fuel availability are all determinants of how often a vehicle owner will have to refuel. Greene and Chin use a value-of-time methodology to determine the value of range and use a national stated-preference survey dedicated to the problem to determine the value of alternative fuel availability. In this case, the Tompkins et al. survey implies that early buyers will be more willing than majority buyers to put up with lower fuel availability, but they will place a premium on range relative to majority buyers. For early buyers, this is a plausible trade-off, if they are to have the privilege of owning a vehicle with low fuel cost.

We find the Greene and Chin functional form for range to be excessively complex and suggest a more readily interpretable 1/x form than the present quadratic form. We recognize that this quadratic model was based on a "best fit" analysis conducted by Greene and Chin. However, noting Greene and Chin's disdain for stated preference, and the fact that this relationship is based on a stated-preference survey, we suggest that this fine point can be reasonably traded off against simplicity. We manipulate the early and late buyer coefficients to give relative values consistent with the Greene and Chin and Tompkins et al. estimates. As it turns out, for hybrid vehicles, the region of the range valuation curve is one in which there is relatively little distinction between conventional and hybrid vehicles. Thus, the added range of a hybrid is not particularly valuable. However, for vehicles with a significantly shorter range than a conventional vehicle, the dollar value of the consumer preference penalty can be very large.

Consistent with Greene and Chin, we drop Tompkins et al.'s multi-fuel availability coefficient. The fuel availability coefficient in Tompkins et al. was statistically insignificant.

We include the home refueling coefficient developed by Greene and Chin and construct coefficients for early group and majority buyers that are consistent with *a doubling in value* for the early group, on the basis that the early group has higher income and higher rates of home ownership. For HEVs with home-refueling capability and at least 10 miles of all-electric range, we assume that this coefficient applies. The home refueling dummy variable in the Tompkins et al. study was also statistically insignificant. However, an estimated coefficient for "off peak" electricity cost when the home refueling feature was available was easily statistically significant, so this result does suggest inclusion of some positive value for home refueling via overnight charging from the electric grid.

5.4 OTHER VEHICLE ATTRIBUTES

5.4.1 Acceleration

The value of acceleration for early buyers, if Tompkins et al.'s coefficients are believed, is about three times larger than the value specified by Greene and Chin and is suggested here to apply to majority buyers. According to the more recent CEC-Morpace study, the implied value of a one-second reduction in 0–60-mph acceleration time for Californians with more than $50,000 of household income is about four times greater than that implied even by the coefficient estimates of Tompkins et al. (Table 5). However, in a footnote, the CEC-Morpace study indicates that a separate test of the value of acceleration indicated a nonlinear relationship, with diminishing incremental value as acceleration time was reduced. Greene (1994) also made the argument that this should be true as cited in Greene and Chin. Considering the high values for acceleration obtained in the CEC-Morpace study for those with household incomes above $50,000, we recommend a value of one-second improvement in acceleration for the earliest buyers (1% share) of $1,000 per second, which is about five times the value Greene and Chin determined.

Because Toyota has recently chosen to advertise and market the combination of performance and fuel economy of coming hybrids to those who read business magazines (e.g., *Business Week*), we suggest that others share the opinion that the early buyer highly values performance.

5.4.2 Luggage Space

We also use the functional form for luggage space (ratio to the Conventional Vehicle) used by Greene and Chin, but we assign a much higher value to luggage space for early buyers, which is consistent with Tompkins et al. We note that the high-mileage drivers who are expected to be early buyers could logically place a higher value on luggage space than the average buyer. One cause of high mileage could be a lot of leisure travel, for which luggage space would be quite important. Another cause is for commercial use of vehicles in sales. Again, if the sales activity requires carrying samples, products for delivery, or other materials related to the commercial use of the vehicle, then luggage space could also be considerably more important than for the average consumer.

5.4.3 Top Speed

Top speed was not included as an attribute by Greene and Chin. The statistical case for it was relatively weak in the Tompkins et al. study. However, the subsequent stated-preference survey by CEC-Morpace did include a variable estimating consumer valuation of sustainable (top) speed on a long continuous grade, and that variable was easily statistically significant (Table 5). Consequently, the argument for inclusion of at least one top-speed variable is strengthened considerably.

HEVs achieve their greatest fuel economy gains when the engine is downsized. Engine downsizing, in turn, tends to reduce top speed and towing capability. FCVs may not have the same trade-off because fuel economy will not benefit as significantly as a result of downsizing the fuel cell. It is even possible that upsizing a fuel cell, in certain configurations, will improve fuel economy. Thus, top speed and towing capability could be distinguishing attributes in the comparison of HEVs and FCVs. If they are not, then these attributes would be important distinctions between FCVs and CVs. Therefore, a value for top speed or towing should be included in the model.

Some unpublished experiments undertaken by using the Tompkins et al. survey data implied that a top speed of over 110 mph was not valued. GM used 110 mph as a design limit in recent vehicle simulations for a joint study with Argonne National Laboratory (General Motors Corporation 2001). The Tompkins et al. joint estimate with California data implied that Californians valued top speed to a greater degree than did drivers in the rest of the United States. We suggest using the Tompkins et al. national coefficient for top speed for early buyers: only up to 110 mph (any top speed above 110 mph is assigned a value of 110 mph). For majority buyers, we suggest dropping the value in rough proportion to the drop in value for acceleration and then dividing that value by 4.6.

5.4.4 Other Features

The ORC International conducted a survey for OPBA on March 15, 2003, that included questions on valuation of (1) ability to operate tools and small appliances and (2) ability to generate emergency power for a home (ORC 2003). Consistent with expectations, the estimated average value for capability 2 exceeded that for capability 1. We assume that the design voltage for appliances is 110 V and for back-up generation is 220 V. There is a distribution of buyers and values, as there is for annual VMT per vehicle. Thirty-eight percent of respondents indicated that they would pay nothing for the ability to generate emergency power, and 44% indicated that they would pay nothing for the ability to operate appliances. The big difference between the responses regarding emergency generation and small appliances was in the value range from $500 to $4,000. Almost twice as many respondents indicated a willingness to pay this much for back-up generation as for the ability to run small appliances. About the same number of respondents indicated a willingness to pay more than $4,000. This difference in consumer valuation of the two attributes can be handled by having the value of the early group coefficient drop more rapidly for small appliances use than for back-up generation. Accordingly, for a given attribute path, the share purchasing because of emergency power back-up will exceed the share for operation of tools and appliances.

A value for the reduction in urban emissions was estimated to be statistically significant for Californians. Because (1) the Prius is considerably cleaner than future Tier II emissions standards require and (2) hydrogen FCVs will have zero tailpipe emissions, we suggest that coefficients be developed on the basis that the vehicle is being sold in metro areas in which air quality is a problem. This recommendation means that the same emissions reduction value would be assigned in all states in which there has been and is still an attempt to adopt California emissions standards. The proportion of gasoline emissions estimated should be the proportion of present-day gasoline vehicle emissions. Also, it might be legitimate to assume that only early adopters would place any value on emissions reduction and have the coefficient drop to zero for majority buyers. The assumption here is that few households are willing to pay for emissions reduction if others are not also required to do so, but the few who will do so would be attracted by this feature of the hybrid. This subgroup would gravitate toward the vehicle and pull the average coefficient for the entire early group up. The advertising for these vehicles is certainly consistent with the hypothesis that altruistic greens are expected to be attracted to the low emissions of these vehicles.

5.5 MAINTENANCE COST

The Tompkins et al. coefficients for the present value of a stream of future reductions in maintenance cost or battery lease cost are consistent with the vehicle owner placing more value on the maintenance and time savings or battery cost than the upfront dollar value of dependability (the maintenance savings) or the lease. We believe that this is a reasonable statement. Although Greene and Chin develop present-value estimates for only the dollar expenditure on maintenance, we note that the need to have maintenance work done on a vehicle requires that vehicle owners invest time. Although Greene and Chin have used the value of time in the value of range estimates, they did not attempt to do so here. Thus, we argue that Greene and Chin underestimate the value of maintenance savings by excluding the dollar value of time required, even for majority buyers.

Consistent with the expectation that the value of time is important for consumer valuation of maintenance costs, we observe that the value of maintenance cost, as estimated in the CEC-Morpace study, is greater for households with more than $50,000 of income, except in households that own three cars (Table 5). The ratio of value of maintenance cost for those whose incomes are above $50,000 to those below is greatest in the one-vehicle household, less in the two-vehicle household, and least in the three-plus-vehicle household. This expectation is likely consistent with the reduced probability of loss of vehicle use during maintenance periods. A two-vehicle household has a greater chance of having use of a vehicle when one requires maintenance than does a one-vehicle household, and similarly, a three-vehicle household has a greater chance than a two-vehicle household. Further, in three-plus-vehicle households where income exceeds $50,000, the chance of having a normally idle spare vehicle is probably highest of all cases.

In light of the high values for maintenance cost obtained in the CEC-Morpace study, and the logical argument that high values are reasonable, we recommend doubling the value obtained in Tompkins et al., to $24 per $1 per year, which is still less than any value obtained in the CEC-Morpace study. For the majority buyers, we recommend using the coefficient value relationship used for top speed and acceleration (i.e., a drop to about 25% of the value) of early buyers to majority buyers. As a result, implied values for maintenance cost are double those estimated by Greene and Chin and are consistent with taking into consideration the value of time.

Some electric vehicle (EV) manufacturers separately leased the battery pack to the buyers of their early EVs. We recommend using the lease cost of the battery pack as the variable to account for the battery component of an EV's cost. If batteries either last longer or come down in cost, the constant model coefficient for this variable will indirectly incorporate the effects of either such change because the lease cost itself will drop in either case.

If the battery pack is purchased and is not expected to last the life of the vehicle, then the net present value savings would be less than those for a hypothetical constant stream-of-maintenance cost savings. For majority buyers, we recommend using Greene and Chin's estimate of 0.63 per dollar of battery cost as a factor to reduce the value of maintenance cost coefficients to account for battery replacement late in the vehicle's life, but before the end of a vehicle's lifetime.

5.6 FAMILIARITY AND CHOICE

At present, the variables "number of vehicles on the road" and/or "make/model diversity" are not included directly in the suggested model. These two variables are related to the same attribute, although there are logical conceptual distinctions. The more vehicles that are available to the consumer, the more satisfied the consumer will be. This assertion applies reasonably enough to majority buyers. If the consumer also wants convenience, reliability, and repair capability at many locations, then even an early buyer might want to have a critical mass of companion owners.

As share expands, both make/model diversity and number of vehicles on the road will increase. Since we are suggesting that the model be designed in such a way that it will have changing coefficients as the share of vehicles with the specified AFV or ATV powertrain increases, effects of increasing share and familiarity may ultimately be incorporated into the model in a manner different from inclusion of either or both of these variables in a normal logit model. Thus, because we address these effects in a computationally different manner (discussed below), to include either of the two measures of positive response with increasing availability would likely risk double counting.

In particular, in the usual logit model, if only two technology options exist (say A and C, for advanced and conventional), and if they are each given only one "slot" in the model, the model inherently assumes that the A vehicle is available in 50% of the market and tends to give it a larger share than makes sense for early introduction. This problem can be addressed (and is in Section 7) by creating tens of slots for C types and only one for A types. The problem then is to create an algorithm that allows more and more of the C slots to be captured over time. This approach had not been tried until now as far as we know. The make/model diversity logic developed by Greene and Chin was a logical surrogate that helped the EIA model reduce estimates of market penetration estimates when only a few models were available. Such a variable may remain desirable. However, it should not be introduced until the properties of the new approaches implemented in Section 7 are examined and early introduction effects are studied.

Comparing the number of vehicles on the road and make/model diversity variables is difficult. However, assume 250 million light-duty vehicles are on the road. Assume that each of the 50 states represents a region. Then each state would have five million vehicles, on average. The variable specification is in terms of thousands of vehicles on the road "in your region." The valuation estimate in Table 1 is $170 per 10,000 vehicles. For the average state, there could be as many as 500 ten-thousand units of vehicles on the road. The resulting value would be $85,000 per vehicle — an absurdly high number — if the effect were carried to its logical conclusion. However, Tompkins et al. asked respondents to consider no more than a few hundred thousand vehicles — not millions. For about 140,000 vehicles in the region, the value would be close to Greene and Chin's estimate for the value of make/model diversity, if all new vehicle makes and models had the type of powertrain in question.

Thus, in terms of make/model diversity, the share of the fleet that makes sense in terms of positive dollar value according to Tompkins et al. is on the order of 3% of the market (140,000 divided by five million). One possibility would be to develop a related variable, the effects of which ends quite rapidly as market share of the technology increases.

Certainly, if the Tompkins et al. coefficient for vehicles on the road has any meaning, it again implies a far higher value for early buyers than for majority buyers. The relevance would be that introducing AFVs and/or ATVs into fleet markets before introducing them into private markets, as many assume is desirable, should have a significant benefit in terms of demonstrating the viability of the technology to early buyers. The shape of the curve selected and fit by Greene and Chin does provide far higher incremental values early in the adoption process than late.

According to Greene and Chin, the penalty for having a powertrain type available in only 1% of makes and models is $2,350. This amount consists of a penalty of $2,000 for having 1% share instead of 50% share and $350 for having 50% share instead of 100%. Greene and Chin proposed using the prior year's share of the market predicted to be held by the powertrain type as a surrogate for shares of makes and models that offer the powertrain type in a future year. One test of this variable is its effect if turned on when hybrids are in the model. The Civic, Prius, and Insight hybrids have already captured a market share of about 0.2% of the new vehicle market. The functional form adopted by Greene and Chin would have costs of far more than $2,350 implied at this market share. Once the model is set up, the incremental effect of this variable could be tested in the event that the model significantly over predicted market shares when attributes of the existing hybrids were plugged into the model. Otherwise, this variable could be left out of the model.

The relationship between familiarity and choice and value could be far more complex than the negative effects simulated by Greene and Chin. At low volumes, exclusivity might be a plus for early adopters. Within the Tompkins et al. paper, Bunch estimated a positive "prestige factor" for selected, low-volume models. Such a variable, however, involves considerable judgment and is not suitable for the AVID model.

Because of the complexity and probable conflicting signals for early and majority buyers, we leave this class of variables out of the suggested model.

5.7 INCENTIVES AND PRIVILEGES

In addition to the attributes discussed to this point, estimates of the value of incentives have been requested. High-occupancy-vehicle (HOV) lane access is one request. The first issue is whether HOV lane access is possible at all. In most of the United States, it is not. However, this privilege is more likely to be available in areas with very congested traffic and air quality problems. Using the value of time savings ($20/h), an assumption of 10 min time saved per trip by using an HOV lane, two trips per day, 48 weeks per year (allowing for vacation, sick days, holidays), the value to a user results in savings of $1,584 *per year*. If one uses willingness to pay as the measure, the implication is that the consumer would pay $6.60 per day to be able to use the HOV lane. Although the time savings might be overstated, it is also possible that the value of time for many drivers is understated, because this is clearly a variable item that should be positively related to driver income. Another way of looking at this privilege would be in terms of avoided stress. If drivers find driving in the HOV lane far less stressful than driving in other lanes, then a dollar premium would have to be assigned to this benefit as well. Clearly, the privilege of using HOV lanes for some drivers could, in principle, far exceed the value of fuel savings from doubling fuel economy. To the extent that value of time is related to income, and income is related to the probability of buying a more fuel-efficient technology (see Table 3), the HOV privilege should nicely reinforce early sales of such vehicles as hybrid electrics.

Another issue is that if the HOV lane privilege is granted, and if the value is as large as indicated, it could accelerate sales of AFVs and ATVs to the extent that HOV time savings would be reduced and the value of the privilege "choked off." Thus, an estimate of the number of additional vehicles that could be served without creating congestion in the HOV lanes would also be needed. Clearly, whatever value is selected for an HOV privilege must apply only to early buyers and cannot be in force when the AFV or ATV is a significant part of the market. So, the majority buyer coefficient should be zero.

The hypothesis that high income is likely to be associated with early buyers was supported in mid-2003 by the reviews of Daniel Heraud on the MSN Autos web site (at now discontinued http://www.carpoint.com/vip/Heraud/). According to his statistics, the average Prius buyer (at that time) had an income of $91,000, an age of 53 years, a 79% chance of being married, and a 63% chance of being a male. For the Camry sedan, comparable figures were $60,000, 53 years, 65% married, and 44% men. For the Corolla, the figures were $49,000, 46 years, 63% married, and 45% men. Although gender is suggested to be a factor, the AVID model does not consider this buyer attribute.

ORC conducted a survey for OPBA on March 15, 2003, that included a question on valuation of HOV access privileges (ORC 2003). Consistent with the general argument in this report that there is a distribution of valuations of vehicle attributes, the values consumers indicate that they are willing to pay exceed $4,000 for 1.7% of respondents, while more than 50% of respondents indicate that they would be willing to pay nothing. The "over $4,000" estimate is consistent with the estimate developed earlier by deductive logic on the basis of the value of time. Three years of savings of $1,584 per year would total over $4,000 of value. We suggest using $4,500 as the value to the early buyer of using the HOV lane privilege. Because more than 50% of respondents say they would pay nothing for the privilege, the value should clearly be zero at 50% share. In fact, we recommend a drop to zero at about 15% share to take into account the probable "choking off" of benefits as HOV lanes become heavily utilized. We doubt that ORC survey respondents considered what they would pay if HOV lanes were nearly as crowded as standard lanes.

The fact that the 2004 Prius can approximately double fuel economy (relative to a mid-size Camry, which is of similar size) and sharply reduce emissions would certainly support use of it in HOV lanes, because the purpose of the HOV lanes (reduced fuel use and emissions per person mile) would clearly be accomplished. The Prius, in particular, would also have the advantage of visual recognition as a unique vehicle deserving the HOV privilege. This privilege could enhance the early adopter "chic" of the vehicle. As of this writing, the State of Virginia has granted an HOV lane privilege to HEVs. In terms of per-capita sales of HEVs in the United States, Virginia led the nation in 2003 (WSJ 2004).

6 CONCLUSIONS ON USE OF STATED- VS. REVEALED-PREFERENCE COEFFICIENTS

A recommendation for a new class of logit models of consumer choice for advanced vehicles has been made and justified. We suggest that recent stated-preference estimates of coefficients determining consumer valuation of advanced vehicles are meaningful if one interprets the results as being influenced by early buyers and early adopters. We acknowledge that the considerably different sets of coefficient values that arise from revealed-preference values are valid for the majority of consumers. Accordingly, to make appropriate use of the information from both stated-preference studies of advanced technology vehicles and revealed-preference studies of contemporary vehicles, a revision of the Advanced Vehicle Choice Model is proposed.

The cited stated-preference findings are informative about behavioral influence of early adopters and early buyers of advanced vehicle technology, while revealed-preference studies are informative about the behavior of the large majority of buyers who will dictate whether or not an advanced technology can completely capture the market. Using variable coefficients as a function of market share, followed by constant coefficients thereafter, would be one possible approach. The approach implemented at this time is not linked to market share, although the pattern suggested is implemented. For the early group of buyers, for the initial iteration of the model, coefficients are proposed that would evolve in value from an initial set toward, but not converging to, a set based on revealed-preference studies, as developed by Greene and Chin. The initial values for the early group would represent preferences of early adopters, while the long-term values would represent early buyers.

As we further discuss in Section 7, the majority group coefficients might move toward the early group coefficients, although to a much lesser degree. As one possibility, the early group would set a “style” standard for the majority group and, in doing so, would alter their preferences somewhat. At this juncture, however, the model is implemented with no change in majority group coefficients over time.

The study has focused on the trade-off between fuel efficiency and incremental vehicle cost, using the 2004 Prius hybrid electric vehicle as a rough benchmark. It has been illustrated that the distribution of vehicle miles of travel per vehicle in the U.S. population (when combined with an estimation of potential net present value of fuel savings for various rates of VMT/vehicle use) provides one logical explanation for some of the differences in price and fuel cost coefficients in stated- and revealed-preference models. This estimation is reasonable if one assumes that (1) the stated-preference surveys that contain new technologies excite early buyers and thus could be used to represent early introduction (a very small market share) and (2) the revealed-preference studies characterize decisions related to purchasing conventional vehicles and could be used to represent preferences of the vast majority of buyers.

The logic that a distribution of preferences implies varying valuations of other vehicle attributes as one moves from market introduction to early adopters and early buyers to eventual expansion to majority buyers is pursued to develop different early group and majority group attribute valuation estimates (coefficients) for several other vehicle attributes included in the AVCM and National Energy Modeling System (NEMS) models.

In light of the promising evolution of advanced hybrid electric vehicle technologies, additional recommendations for some new coefficients have also been made, on the basis of surveys conducted for OPBA's transportation analysis and for its predecessor. Early buyers provide positive valuation for these coefficients for the right to use an HOV lane, for the ability to run small appliances from the vehicle's electrical system, and for an ability to provide back-up power for a house. For three of the added coefficients, early buyers have been estimated to place a relatively high value for the attribute, but the majority of buyers are assumed to place zero value on the attribute. Differing rates of decline of the coefficient values to zero as market share increases have been proposed.

We suggest that future surveys be constructed and analyzed in a manner that would allow further testing of the hypotheses developed here. One simple approach would simply be to (1) ask respondents if they considered themselves early adopters fascinated with unique technology and then (2) conduct statistical analysis for three different samples — with and without self-identified early adopters and with both. Other checks of respondent behavior might also be in order. Whether or not a vehicle is added or replaced could be one line of demarcation. Another might be to examine stated willingness to spend money on hypothetical vehicles by analyzing actual behavior, as revealed by vehicles presently held by the household. Very unusual responses within stated-preference surveys should be identified, and the influence of such responses should be tested. Finally, we reiterate that revealed-preference surveys seem unlikely to provide the necessary information for early consumer reaction to very unique advanced technology vehicles.

7 BUILDING A MODEL OF ADVANCED VEHICLE INTRODUCTION DECISIONS (AVID) USING STATED- AND REVEALED-PREFERENCE STUDIES OF CONSUMER BEHAVIOR AND ADDING KEY PRODUCER DECISIONS

7.1 OVERVIEW

In this section, we describe the procedures programmed at present for the Advanced Vehicle Introduction Decisions (AVID) model in an MS EXCEL workbook. The rationale behind and background relating to the model have been described earlier. We discuss many specifics of implementation.

7.1.1 Multinomial Logit Models

Four multinomial logit models — one for the early group and the other for majority buyers — are applied, and within those two categories, one is "unconstrained" and another is "production constrained." Results are recomputed every year, to take into account changing consumer-preference coefficients, changing vehicle attributes, changing fuel prices, and advanced powertrain production decisions. The results of projections for the early group and majority buyers are combined into total constrained and unconstrained share estimates for a specified year, with a weighted average accounting for the size of the two groups. The unconstrained share is an estimate of the long-term potential (propensity to buy) for advanced technology penetration, while the constrained estimate provides the current share of the market, considering availability constraints for the new powertrain type. As long as the current unconstrained long-term potential share estimate exceeds the production-constrained share, vehicle manufacturers are simulated to add advanced powertrain options to more makes and models.

An iterative procedure is applied to update the early group model coefficients so that they move toward the majority group coefficients. During the first iteration, coefficients adapted from recommendations in Section 5 are applied for early group and majority-buyer models. Table 7 lists starting coefficients for the two models applicable to the small car. These coefficients are not uniformly identical to those in Table 1. The coefficients are developed by using the suggested values in Section 5. Further, the coefficients are only an initial set, for one class of vehicle. Multiple sets of coefficients for multiple classes of vehicle will be developed in the future when the AVID model is expanded and refined.

When applied to a set of new technology (NT) vehicles and conventional vehicles (CVs), the early group multinomial logit will be applied, as shown in Equation 1.

TABLE 7 Starting Coefficients for the Early and Majority-Buyers Models Applicable to Small Cars

		Early Group Model		Majority Buyers Model	
Vehicle Attribute	**Unit**	**Coefficient**	**Implied Value ($)**	**Coefficient**	**Implied Value ($)**
Vehicle price	2005$	-0.000020	-1.0	-0.0017927	-1.0
Fuel cost	2005 cents/mi	-0.036000	-1,800.0	-0.85153	-475.0
Range	1/mi	-0.224000	-11,200.0	-207.1985	-115,580.0
Battery replacement cost	2005$	-0.000002	-0.1	-0.00113	-0.6
Acceleration, 0–60 mph	s	-0.020000	-1,000.0	-0.389013	-217.0
Home refueling	Dummy	0.027000	1,350.0	1.210062	675.0
Maintenance cost	2005$/yr	-0.000480	-24.0	-0.009322	-5.2
Luggage space	Ratio to CV	0.282000	14,100.0	3.22683	1,800.0
Fuel availability	1/Ratio to Gas	-0.000354	-17.7	-0.13445	-75.0
Top speed	mph	0.002240	112.0	0.04365	24.3
Emergency home power	Frac equipped	0.080000	4,000.0	0.008963	5.0
HOV lane exemption	Frac exempted	0.090000	4,500.0	0.003765	2.1
Electric outlet for tools	Frac equipped	0.008000	400.0	0.006274	3.5

$$S_{VE} = \frac{\sum_{A=1}^{N} EXP(E_A \times Q_{VA})}{\sum_{V=1}^{All} \sum_{A=1}^{N} EXP(E_A \times Q_{VA})} \tag{1}$$

where:

S_{VE} = Market share for vehicle technology *V* projected by model *E* (early group),
E_A = Model *E* (early group) coefficient for attribute *A,*
Q_{VA} = Quantity of attribute *A* for vehicle technology *V,* and
N = Number of vehicle attributes (13 in Table 7).

7.1.2 Small Car Attributes

Although the model can be applied to several vehicle technologies simultaneously, we applied it to two technologies for the initial tests: CV and HEV. Attribute quantities for the small car were generated for years 2000 through 2050. CV prices were taken from the Annual Energy Outlook (AEO) 2003. The HEV was assumed to cost 30% more than the CV in 2000. The HEV price was assumed to decline 1.3% per year for 15 years and stabilize at 107% of the CV price. The HEV was assumed to have a range 25% greater than that of the CV and 91% of the CV's top speed and luggage space. The HEV fuel economy was assumed have 150% the fuel economy of the CV in 2000, and fuel economy was expected to increase to 175% by 2015 and beyond. All other attributes were assumed to be equal for this test. Figure 9 shows ratios of HEV attributes to CV attributes.

7.1.3 Time Dynamics

In the following description, we discuss only two vehicle technologies — the HEV denoted by H and CV denoted by C. We also introduce an iterative procedure to reflect that after a few years following a new technology's entry in the market, the early group's preferences tend to move in the direction of the majority group's preferences. Also, if a new technology were not constrained by the number of its make and model combinations actually produced, it would compete with CVs solely on the basis of its attributes. We term this theoretical market share (which ignores the lack of availability of hybrids in many makes and models) as the share resulting from buyers' "propensity to buy" and denote it by $\hat{S}$. Actual production is generally less than or equal to this share. Production moves toward this share over time.

7.2 CONSUMER MARKET SEGMENTATION, SHARE PREDICTIONS, AND COEFFICIENT ADAPTATION

Although the proposals in this report might imply three sets of preference coefficients for subgroups of the population, the fact is that available information would not allow this level of detail. In particular, the stated-preference studies done to date would not allow the development of separate sets of coefficients for early adopters and early buyers, and they appear not to

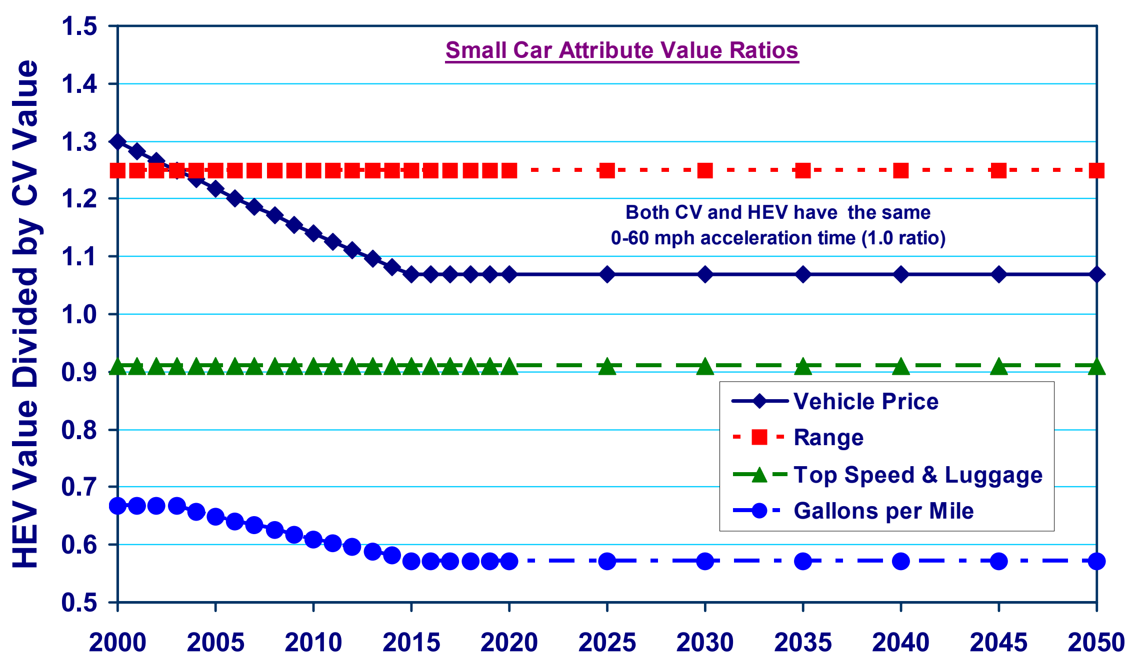

FIGURE 9 Assumed HEV Attributes Relative to CV

represent majority buyers. In effect, our opinion is that the coefficients of the recent CEC-Morpace study and the earlier Tompkins et al. study actually are better representatives of a blended coefficient set representing an average between early adopter and early buyer behavior. Coining a term for this subset of buyers, we have called it the early group of advanced technology purchasers — or simply the "early group coefficients" (symbolically, E). The second set of initial coefficients would be the conventional technology majority coefficients or "majority coefficients" (symbolically, M).

We argue that, as a relatively successful and clearly unique technology is introduced into the market because of the preferences of an early group of buyers, the majority buyers become educated about the potential of the technology and adapt their opinions about it. Thus, as the early group buyers increase their share of the advanced technology, the initial conventional majority changes and adapts its knowledge about the technology. The system that we suggest treats a new advanced technology separately from conventional technology for a number of years, but as the new advanced technology reaches its equilibrium share of the market, the early group coefficients move toward the majority group coefficients. However, for reasons explained earlier, it is not appropriate for them to completely converge, especially where vehicle price and fuel cost coefficients are concerned.

The notion that consumers will become more receptive to a new vehicle technology if only they are better educated about how to use it is not new. Kurani, Turrentine, and Sperling (1994, 1996) showed that this hypothesis should be correct for a subset of possible households owning electric vehicles. One big problem to be overcome for electric vehicles was limited range and long refueling time. They conducted extensive interviews with members of multi-vehicle households to determine how behavior could be adapted to allow a conventional vehicle to be replaced with an electric vehicle. Kurani, Turrentine, and Sperling showed that, for multiple-vehicle households, this particular shortcoming could often be managed effectively. After interviews and examination of vehicle-use patterns of individual households, they showed that the receptivity to electric vehicle ownership by multiple-vehicle households would increase.

Graham et al. studied hybrid consumer preferences that adapted estimates of a hybrid vehicles fuel cost savings to the unique driving behavior of the household. This study included an examination of grid-connectable or "plug-in" hybrids, which would have characteristics of both electric and gasoline vehicles. In addition, Graham et al. studied consumer response to hybrids of the type examined in the majority of this report.

An attribute of hybrids that had not been illustrated to respondents in the Tompkins et al. and CEC-Morpace studies is that fuel efficiency increases are greater in stop-and-go urban driving than in highway driving. The Graham et al. study asked respondents about their commuting patterns, developed suitable fuel savings estimates related to those patterns, and then asked the respondents their receptivity to those fuel cost reductions specific to their driving. The study also involved interviews of consumers in four major cities: Atlanta, Boston, Los Angeles, and Phoenix. Such cities are locations in which the advantages associated with comparative fuel savings of the hybrid technology should be larger than those for smaller cities and rural areas. Each of these cities has violations in air pollution standards and requires gasoline adapted to reduce emissions. Gasoline prices are higher in such cities, both because of the cost of clean gasoline and higher taxes. The study thus assumed a gasoline cost of $1.65/gallon, which is somewhat higher than national averages over the last several years. Further, the Graham et al. study did not simulate reductions in top speed for hybrids.

On the basis of the CEC-Morpace and Tompkins et al. studies, this omission — in combination with interviews of respondents only in major congested urban areas — should have been to the advantage of the hybrid technology. Base-case market shares predicted for a hybrid powertrain in a mid-size vehicle were 35% for both a grid-independent hybrid and a grid-connected (plug-in) hybrid with 20 miles of all-electric range. The study invested considerable effort in the characterization of the cost and fuel economy of the hybrid powertrains in conventional vehicle bodies and used those results to set base-case costs and fuel economy.

Although 35% might seem high, it is noteworthy that Denny Clements, general manager of Toyota's Lexus luxury division, was quoted by the *Chicago Tribune* (Popely and Mateja 2004) as saying that "we're looking at 20 to 25 percent of the mix as an early indicator" for the coming RX400H hybrid, which is to be a part of the "RX" Lexus SUV model line. Such an expectation could be broadly consistent with the Graham et al. study estimates, if sales shares in congested urban areas are the highest to be expected (35%), while shares might be much smaller in rural areas and smaller cities (10–15% perhaps?).

7.2.1 Expectations Adapted to Offerings

Kurani et al. (2004), Kurani and Turrentine (2004), and Turrentine and Kurani (2005) recently investigated consumer decision making about automotive fuel economy. They considered consumer valuation of a relatively dramatic improvement in fuel economy (50%), such as is possible with a hybrid like the Prius. They conducted thorough interviews and reported on themes in the interview responses. According to their research, consumers expect that reducing fuel consumption also means reducing vehicle cost, luxury, and power. The reason for this expectation is that it is a characteristic of the existing fleet. Buying a more fuel-efficient model, at a minimum, means choosing a smaller engine in a given vehicle, or it might mean choosing a smaller vehicle. Similarly, if a consumer wants four-wheel drive, but also wants fuel economy from the same vehicle, then one trade-off would be to purchase two-wheel drive rather than four-wheel drive, thereby spending less on the vehicle.

The hybrid powertrain will alter these trade-offs completely. In academic terms, the consumer will be provided with another degree of freedom or dimension in the array of trade-offs between fuel economy and vehicle performance. With the hybrid technology, more expenditure can mean both better performance and better fuel economy. So, in effect, the consumer will have to "unlearn" previous "facts" about the trade-off between vehicle performance and fuel economy. No study that we have examined has been designed to obtain an understanding of how the consumer will respond to a trade-off that allows both more performance and higher fuel economy. Toyota is using this marketing strategy for its 2005 HEVs. However, studies have been done to address the fact that an increase in cost with constant performance capability can increase fuel economy with a hybrid powertrain.

7.2.2 Manipulating Consumer Behavior as the Market Changes

A key argument here is that, unlike standard economic theory, preferences are not fixed. Preferences change as the market changes and as new information about new technology is obtained. As noted earlier, Bass (1980), discussing technology diffusion, used an analogy of "contagion" models from epidemiology and essentially termed everyone but early adopters (his innovators) as "imitators." Advertising and fashion executives certainly believe that preferences are alterable and that leaders can establish a new trend supporting market success.

One of the concerns with contagion of diseases is that a virus will adapt in a way that accelerates and expands an outbreak. In a sense, producers would prefer to manipulate and alter consumer behavior in such a way that market success would be enhanced. We assume that producers recognize early adopters as market leaders — or as the first "hosts" to promote a contagious response to the new technology.

The model assumes that early adopters are the first target for producers. An input to the model is the number of years for which the initial early group coefficients — the early adopter coefficients — are held constant. At some point, as the new technology is introduced and becomes more commonplace, early adopters will begin to (1) exit the market or (2) reduce their degree of interest attributable to uniqueness of the technology (see discussion below).

When introducing a new powertrain technology, vehicle producers are both attempting to learn what they can accomplish technically and in terms of cost with the technology and how consumers will respond. Absent public policy, the powertrain technology will be introduced initially because manufacturers expect that a profitable market for the technology exists. On the basis of the discussion in this report, the first customers who are targeted are early adopters. These are vehicle purchasers who value uniqueness. To take advantage of this preference, manufacturers tend to package initial powertrains in a unique vehicle, as was the case with the Insight and Prius hybrids. The first rotary engine was also packaged in its own unique vehicle, and so was the first U.S.-manufactured front-wheel-drive vehicle, the 1960s Oldsmobile Toronado (Wards 1967). Several years later, front-wheel drive was widely successful. The rotary engine was scheduled to be introduced by GM in a mass-produced economy car in the early 1970s, but rising oil prices shelved those plans (Wards 1976).

After enthusiastic early adopters accept and promote a new technology, manufacturers must then introduce the powertrain as an alternative in standard models — if its attributes justify this market transition. It is this latter step that is of most interest from a public policy perspective, because success or failure at this stage dictates the potential for the full market. Hybrids are now at this point.

As has been noted, the early adopters within the early group are the ones that cause the price response to be limited. From the perspective of producers, they are a desirable test market for a new technology because they are willing to pay a high price for a unique product. However, as the share of the product in the market increases, the early buyers are the next segment that must be captured. These are more price-sensitive buyers. However, depending upon the attributes of the technology, they may also be in circumstances that match the technology well.

So, to realize an increase in market share, the price must come down because price is more important to early buyers, and uniqueness of the vehicle is less important. The powertrain will have to sell — at a reasonable price — to these "rational" customers on its merits. The price sensitivity will increase, and the relative willingness to pay for other positive attributes (or penalize a vehicle with negative attributes) will drop. Therefore, cutting costs and increasing quality via mass production and learning is imperative for producer success.

For majority buyers, most will be reluctant to buy or will judge the initial technology to be incompatible with their needs, on the basis of limited information. As the early group purchases more of the new powertrain technology, more and better information on the attributes will be found by word of mouth and in the media. Those customers unwilling to spend a lot of time learning about the technology will learn about it with much less effort than customers considering the technology early in the market-introduction period. Some within the majority will realize that the technology does match their needs and will readjust their expectations. In effect, assuming generally positive improvements in the technology as share increases, the preferences of the majority toward it will improve. There may even be a "keep up with the Joneses" effect. So, although not simulated at present, the preferences of the majority could move toward those of the early group.

One aspect of the producer strategy that is implicitly, but not explicitly, incorporated into the model is the tendency to incorporate first versions of new powertrains into unique vehicle models. The producer model is rudimentary and assumes that producers simply examine the total potential market and respond to it, rather than explicitly attempt to manipulate the market as discussed above. However, the consumer preferences model does allow the number of years for which early adopters remain interested in the technology to be specified. If this period is one during which unique vehicle models dominate, then it can be said that "uniqueness" effects are implicitly considered. For a particular technology, those attempting to apply the AVID model could track the stated strategies of producers when making decisions about how long to simulate market domination by early adopters. If switching from unique vehicle models to everyday models is the test, then early adopters of hybrids are about to begin exiting the market, and the "acid test" for hybrid powertrains is about to start.

Once a decision has been made to begin a simulated shift of early adopters out of the market to a condition in which the early group is dominated by early buyers, two decisions have to be made, in principle, for each set of attribute coefficients:

1. What is the anticipated value of an attribute for early buyers, in contrast to majority buyers?
2. How rapidly does the influence of early adopters disappear from the market?

The present strategy for the model is to think in terms of changes of dollar values of attributes and work backwards to develop appropriate coefficients. Price sensitivity is the first coefficient readjusted, and then dollar value changes are estimated for each attribute and, in turn, converted to coefficients. The present assumption is that early buyers value attributes that are somewhere between those of early adopters and majority buyers. The model essentially allows the percentage of the difference between these two groups to be chosen.

V = dollar value of a vehicle attribute;
a = subscript denoting a particular attribute;
e = subscript denoting early adopters;
b = subscript denoting early buyers;
m = subscript denoting majority buyers; and
f = fraction of difference between early adopter and majority values for the early group, once the early group is dominated by early buyers (recommended values are less than 0.5).

$$V_{ab} = f \times (V_{ae} - V_{am}) + V_{am}$$

The next task is to determine how quickly early adopter preferences will shift to early buyer preferences. This value is determined by selection of a decay factor for exponential decline. The effects of a range of decay factor choices are illustrated in Figure 10, and the general concept of evolution of dollar value of fuel savings is illustrated in Figure 11.

7.2.3 Model Development and Calibration: Tests Predicting the Consumer's Long-Term Desired Shares for the Early Group and the Majority Group

Initial tests of the coefficients were conducted for pairs of powertrains — one conventional and one hybrid. This test, as we discuss below, provides estimates of the share of hybrids for the early and majority groups that should be regarded as the current best

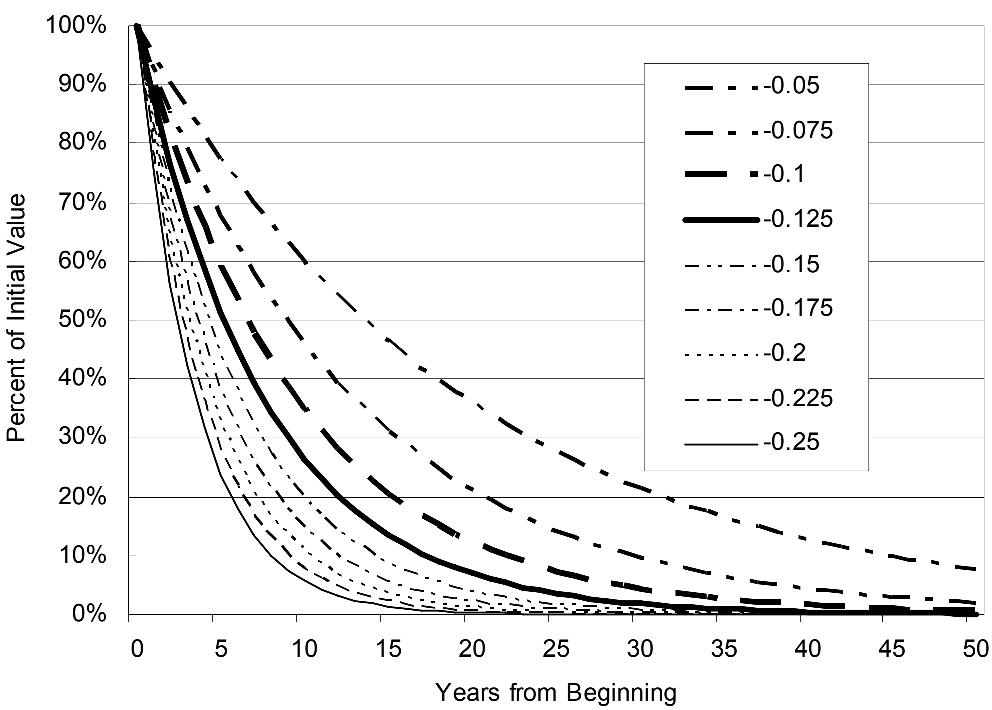

FIGURE 10 Effects of Various Annual Rates of Annual Decay over 50 Years

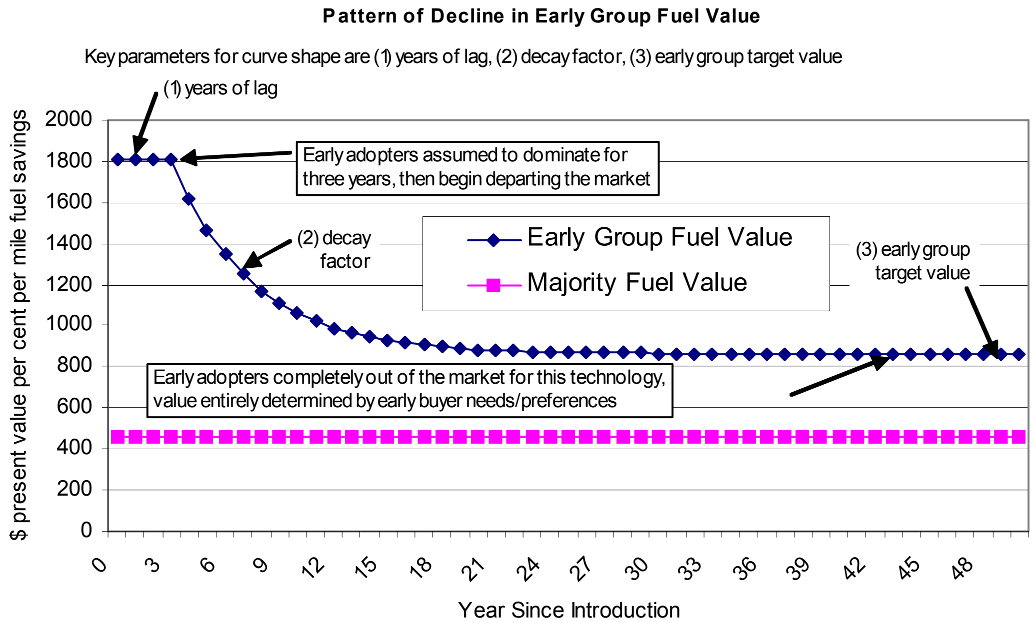

FIGURE 11 Illustration of Evolution of Early Group Attribute Values over Time

understanding of the long-term desired share if both hybrid and conventional powertrains were available in every make and model of vehicle. However, this scenario may take a long time for producers to make possible.

Although the focus of this report is on understanding consumer preferences, to make our model behave according to "a priori" expectations, we must also simulate producer behavior, which we discuss in following pages. The share predicted "as if" hybrid powertrains were made universally available in all makes and models will be named the "producer long-term target share." We assume that, as producers develop advanced technology, they can also conduct consumer surveys of their own to establish the ultimate market potential of the technology. If that potential is estimated to be high enough to justify production of the technology, then the long-term goal is to capture a significant share of the ultimate target market, recognizing that competitors are likely to also adopt the technology.

In an early experiment on the consumer's implied long-term desired market share for hybrids, the attributes of the 2001–2003 Prius, in comparison to a composite average of attributes for the Corolla and Echo models (competing subcompacts within the same make), were entered into separate models for the early group (coefficients similar to those of Tompkins et al. and the recent CEC-Morpace study and the majority (coefficients similar to those of Greene and Chin). The early group was predicted to select a hybrid vehicle with this Prius model's attributes over 40% of the time, while the majority was predicted not to select such a hybrid vehicle at all.

Both results are clearly inconsistent with reality. For example, 2003 sales of the Echo were 26,167, the Corolla 237,597, and the Prius 24,627. Thus, the Prius held about 8.5% of the market for Toyota compact sedans (the Civic hybrid held 7.2% of the 2003 Civic sales). With respect to powertrain and transmission combinations, there were five among these three vehicles, so the Prius held considerably less than its 20% share of these powertrain choices (the Civic line had nine powertrain and transmission combinations, two of which [22%] were hybrids). Once a long-term, low-cost vehicle was specified (10% cost increment instead of over 50%), the *majority* coefficients implied a long-term share of about 8%, which seems low in light of recent Prius and Civic hybrid compact sedan "own-make" (a manufacturer's respective make or brand, e.g., the Prius share of all Toyota compacts and the Civic hybrid share of all Honda compacts) shares attained with far higher price increments.

There are several possible responses to the above statistics. One is that the model's prediction of a consumer's long-term desired market share for hybrid powertrains was too high. However, we know that Honda and Toyota plan to expand their hybrid powertrain options in future years. Consequently, an alternative implication is possible — that the market's desire for hybrid powertrains was not fulfilled in 2003, and Honda and Toyota learned that they could expand it considerably. This is the interpretation that we are building into the model. Clearly, if the revealed-preference coefficients were correct, and zero sales should be expected for majority buyers, then Toyota and Honda would exit the U.S. market. However, if the stated-preference coefficients are reasonably valid, then the customer surveys that Toyota and Honda are conducting are more consistent with these coefficients than with the Greene and Chin revealed-preference coefficients, indicating that expansion of the market is possible.

Nevertheless, according to the arguments in this report, we do not believe that the full population desires either share estimate. Rather, we assume that these share estimates represent two subgroups within the population, and the long-term desired share for the full market is some sort of weighted average of the two share estimates. During the transition to a new powertrain technology, the customer base in the model developed here is divided into two groups: the early group and majority. The weighting factor, the percent of early buyers (P_E), will be specified in the initial version of the model as an exogenous fixed value.

7.2.4 Reconciling Long-Term Consumer Desires with Near-Term Vehicle Availability

The nature of multinomial logit modeling (mnl) is that shares predicted are dramatically affected by the number of alternatives offered. In the share estimates constructed above, we implicitly assumed that conventional gasoline and hybrid powertrains were equally available, which was the condition that respondents to the Graham et al. survey were asked to imagine, resulting in a 35% share estimate. However, this estimate simply measures market potential and does not reflect near-term sales share opportunities. Why not? Initial shares are small because the availability of hybrid powertrains is very limited, and the choice of hybrid powertrains is probably secondary to make and model. We also saw that the present offerings of hybrid powertrains within the compact sedan segment for Toyota and Honda was not equal; considerably more conventional powertrain options are available than hybrid powertrains. Finally, at least for the 2004 Prius, the evidence at this time is that demand considerably exceeds supply, thus limiting the share realized.

7.3 ADAPTING PRODUCER BEHAVIOR AS THE MARKET DEVELOPS: ESTABLISHING PREDICTED SHARES OF THE MARKET RELATIVE TO LONG-TERM ATTAINABLE SHARE

As noted earlier, the logit model has the property that the share predicted depends on the number of alternatives offered. The long-term desired consumer share results from a logit model in which a conventional powertrain and a hybrid powertrain compete against one another on an equal-availability basis. However, this scenario is hardly what consumers face when a new powertrain type enters the market. A consumer's highest priority, in most cases, is the choice of make and model rather than powertrain. Thus, if an advanced powertrain is not available in many makes and models, consumers with a strong interest in those makes and models will simply not consider the powertrain type.

We counted 225 makes and models listed in the J.D. Power Sales Report (Power 2001). Two of these makes and models — the Toyota Prius and the Honda Insight — actually are models that only offer a hybrid powertrain. The Honda Civic, however, has multiple powertrains, including a hybrid option. All (announced) upcoming hybrids that we are aware of will include a hybrid powertrain as an option, in addition to conventional powertrains. If we treat the Honda Insight as a money-losing, image-making, non-commercial hybrid vehicle, then of the 225 makes and models, there are two hybrid powertrains that are apparently intended for profitable commercial success: the Civic hybrid and the Prius. If one assumes that consumers go through a sequential vehicle selection process in which they choose the make first, vehicle size second, and the powertrain type third, the hybrid option will be selected only if it is available. Consumers therefore choose the hybrid powertrain after they choose Honda or Toyota and after they choose the compact sedan car styles produced by Toyota and Honda. Assuming that consumers consider the hybrid option at the end of the vehicle-selection process, the apparent market for hybrid vehicles is small — if two of 225 makes and models have hybrid powertrains, the choice is a subset of 0.9% of the market, or about 147,000 vehicles in a 16.5-million-vehicle market.

The Prius and Civic hybrid sold 46,400 units in 2003, which is about one-third of the approximated 147,000-vehicle market. This number is below the 40+% share predicted earlier for long-term early group consumer desires, if hybrid powertrains and conventional powertrains were equally available. Yet, it is above the weighted share for early group and majority buyers (see below). This finding illustrates that accounting for competition against all makes and models in the market can lead to a reasonable order-of-magnitude approximation of the share of hybrid sales currently attained. When the range of interest is four orders of magnitude (10,000 to 17,000,000), "within an order of magnitude" seems a reasonably satisfactory and logical approach.

The point is that the only way that one can obtain a realistic prediction (within an order of magnitude) of the sales volume of the available hybrid in the U.S. market is to use an approximation of the competition against all makes and models. Vehicle producers are the decision makers responsible for deciding how many make/models will have a hybrid powertrain.

7.3.1 Determining Introduction of Advanced Powertrains by Producers

If the share of hybrid powertrains predicted to be the long-term desire ($\hat{S}_H$) exceeds the share of hybrid powertrains recently sold in the full market (S_H), then producers will add more hybrid powertrains to the market. The producers are assumed to be cautiously testing a selected incremental expansion of the market to a target share increase that could be much less than the difference between the predicted attainable long-term share and the recent total market share.

Let R_H = fraction of estimated remaining market scheduled for new make/models with HEV powertrains,
NT = new powertrain technologies (hybrid, diesel, fuel cell, etc.),
MC = number of make/models with conventional powertrains,
MH = number of make/models with hybrid powertrains,
MNT = number of make/models with a new technology powertrain,
N^n_{MH} = number of HEV make/model combinations at iteration n, and
N^n_{MC} = number of CV make/model combinations at iteration n.

The change in make/model combinations is determined by the difference between consumers' long-term desired share and the current share constrained by make/model availability.

Define Y as the time interval over which manufacturers think they could schedule about 80% replacement of powertrains in the most extreme of circumstances (10 years assumed here).

Define the fraction of HEV make/models to be added per year as:

$$R^n_H = \frac{\hat{S}^n_H - S^n_H}{0.25 \times Y} \tag{2}$$

Total fraction of remaining market to obtain advanced powertrains for all new technologies at year n is defined by:

$$R^n = \sum_{NT=1}^{NT=All} R^n_{NT} \tag{3}$$

The number of HEV make/model combinations available at iteration n+1 is given by equation 4:

$$N^{n+1}_{MH} = N^n_{MH} + Average(R^{n-3} through R^n) \times (N^{n-3}_{MC} + N^{n-3}_{MH}) \tag{4}$$

Note that the user specifies the number of make/model combinations (MC) during the introduction year. In the model as presently set up, *MC>=MNT>=MH*. At present, the model does not include a way to account for make/models designed specifically to take advantage of the attributes of a particular new-technology powertrain. In effect, the model in its initial setup does not allow for a make/model such as the Prius. It does not allow for the possibility that new powertrain technologies could cause an expansion or contraction of make/models available, even though this has clearly happened with the Prius and Insight. Looking forward, however, we see the most likely path to mass-market penetration by hybrid and diesel powertrains is as optional powertrains in current makes and models. Thus, we set up the model to behave as if this presumption is correct.

Thus, if a hybrid powertrain is available in every make and model, then $MC = MH$. This neglects the current situation in the Civic model line, in which a hybrid powertrain is available, but within the model line, $MC>MH$. Obviously, the model is a studied approximation of reality.

Over the years, we have been involved in studies of market penetration rates of various vehicle technologies and have estimated equations simulating smoothed rates of introduction according to the logistic function (Santini 1989; Wang et al. 1997). A problem that we have noted in the literature applying the logistic function methodology is that the basic concept used involves an assumption that 100% of some market is attained, but it often cannot define what the ultimate size of the market is. In other words, an "S-" shaped function is fit from 0% to 100% of a market, the size of which is known retrospectively. But there is no method to predict the ultimate size of the market. In this model, our estimation of the long-term desired share solves this problem in principle. Historical market switches, to which logistic functions have been fit, suggest that a flattened "S" shape is the appropriate pattern to expect for a successful technology.

In Figure 12, we reproduce the pattern of introduction of front-wheel-drive (FWD) powertrains in U.S. passenger cars, reproduced from Wang et al. (1997). Recall that the Oldsmobile Toronado FWD vehicle was available as early as 1966. Thus, FWD technology remained a small share of the market for more than a decade, before being pushed forward by refinements and increasing fuel prices in the 1970s. In contrast, the rotary engine had also been available before the early 1970s, but oil price increases killed that technology rather than pushing it into the market.

What can be seen in this figure is that there is an initial period of five years in which the FWD powertrain holds a small share of the market and then "takes off" to over 40% of the market within the next three years. Note the similarity to Figure 1. After a year of "hesitation" in 1979, steady growth in FWD continues for about a decade to an ultimate representation of a bit above 80% of the auto market. It can also be seen that the usual logistic function fit goes to 100% instead of a bit above 80%. For our purposes, items of interest are the early evaluation period before the take-off and the length of time from about 10% of the ultimate market to 90%. We count this interval to be about ten years. We set the value of Y = 10 in the default model. During most of the time interval involved, real gasoline prices significantly exceeded gasoline prices from 2000 to 2003. Using this as a target behavior for the model, we assumed that 10–90% penetration of hybrid powertrains, up to the estimated ultimately desired level within a decade, would be an acceptable behavior of the model under relatively optimistic assumptions about hybrid fuel savings and incremental cost.

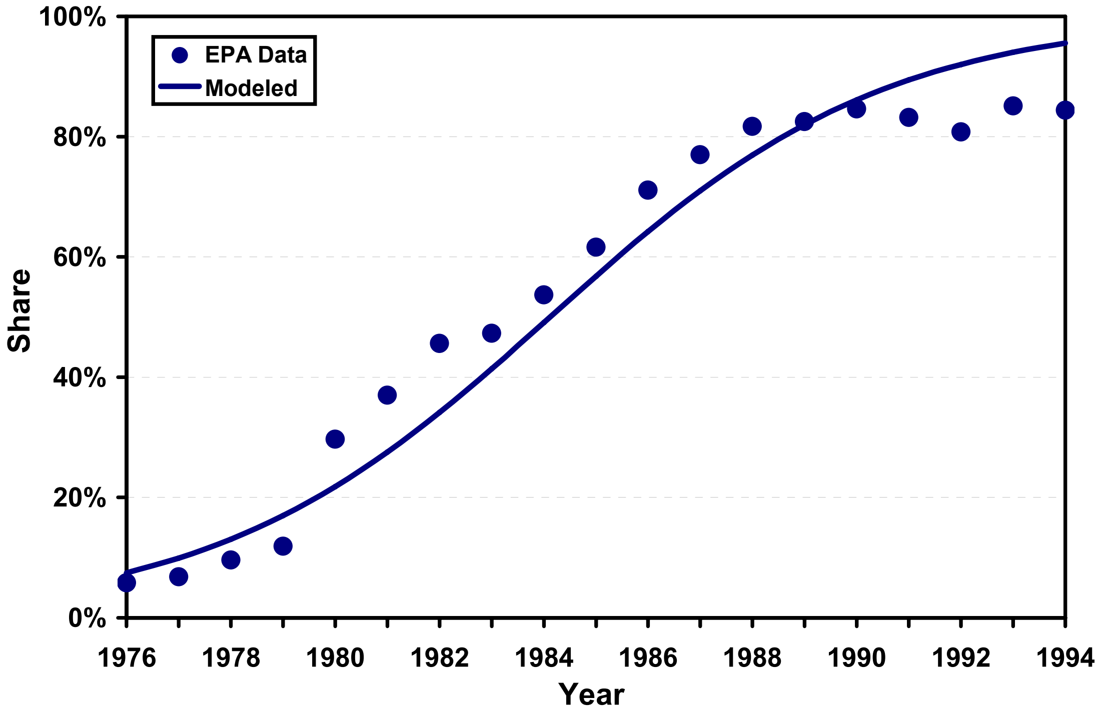

FIGURE 12 Market Share of Front-Wheel-Drive Autos in the United States, 1975–1994

One of the "levers" that affects this rate is the assumed fraction of the remaining market to be served (R_H) that auto producers attempt to serve, after the initial period of evaluation of the technology. By multiplying the denominator Y in equation 1 by various coefficients, we tested the sensitivity of the market's rise to this value, settling on a value of 0.25. On the basis of this value, the desired share of the *ultimate* market ($\hat{S}_H$) that producers would attempt to serve would be a maximum of 40% in the initial year. As a simplified illustration, if an oil price shock (like the one that occurred from 1978 to 1979) prompted consumer propensity to buy FWD vehicles to rise to 60% of the market from 10% of the market, then manufacturers (after the lag incorporated in the model) would attempt, in the first year of production, to increase the (available) capability to produce FWD models by 20% of the market (40% time [60–10%]). So long as S_H is greater than zero, the actual percentage of the ultimate market remaining would be less than 40%. Note that as S_H increases over time, for a given level of technology, the size of the remaining market to be served diminishes. This phenomenon causes the bending shape at the top of the "S" curve.

In most cases, during the introductory period when a new powertrain technology is developed and successfully refined, the estimated ultimate market $\hat{S}_H$ will actually expand. Thus, for any given year, changing technology attributes, changing fuel prices, and prior investments in the production of powertrains with new technology will interact to affect the planned rate of expansion of makes and models offering the new advanced powertrain.

The expansion of number of advanced hybrid powertrain offerings is actually predicted by equation 4. Instead of using a single year's estimate of R, we use an average of R over a four-year period. We assume that producers make decisions deliberately and account for general patterns of preference that they expect to be sustained. Given the method of estimating S, for example, if oil price jumped for one year, and we simulated a response to each year's estimated value of $\hat{S}_H$ less S_H, then rapid increases and decreases in make/models with hybrid powertrains would be predicted by the model. We do not think such behavior would realistically simulate the market, but we do think there is much more "momentum" involved in decisions to introduce or delete powertrain options. Thus, we use the multi-year average.

Initial tests of the model started with a specification of two makes and models of hybrid. Because of lags built into the model, the share of the market did not take off until eight or more years had passed. Note that we have not at this time programmed incremental vehicle cost as a function of time and volume produced in sub-models, as discussed in Section 7.4.

7.3.2 Determining Long-Term Desired Share by the Early Group and Majority

Recall that early group coefficients are denoted by E_A in equation 1 (in Section 7.1.1). The initial early group coefficients in Table 7 are modified iteratively. We add notation *n* for iteration (year) and denote the coefficients as E_A^n. Although the majority group coefficients do not change over time, we denote them identically as M_A^n.

Let H_A^n = HEV attributes (corresponding to E_A^n and M_A^n) and
C_A^n = CV attributes (corresponding to E_A^n and M_A^n).

Long-Term: Early Group. The long-term desired HEV powertrain share of the early group at iteration *n* is given by equation 5.

$$\hat{S}_{HE}^n = \frac{EXP(\sum E_A^n \times H_A^n)}{EXP(\sum E_A^n \times H_A^n) + EXP(\sum E_A^n \times C_A^n)} \tag{5}$$

Long-Term: Majority. The long-term desired HEV powertrain share of the majority at iteration n is given by equation 6.

$$\hat{S}_{HM}^n = \frac{EXP(\sum M_A^n \times H_A^n)}{EXP(\sum M_A^n \times H_A^n) + EXP(\sum M_A^n \times C_A^n)} \tag{6}$$

Long-Term: Full Market. The combined early group and majority buyer long-term desired HEV market share at iteration n is given by equation 7.

$$\hat{S}_H^n = P_E \times \hat{S}_{HE}^n + (1 - P_E) \times \hat{S}_{HM}^n \tag{7}$$

7.3.3 Determining Current Year Actual Share by the Early Group and Majority

Current Year: Early Group. The actual current year HEV market share is constrained by the number of make/model combinations that include an advanced powertrain option. The market share for the current year (at iteration n) HEV purchases by early buyers and adjusted according to make/model/powertrain availability is given by equation 8.

$$S_{HE}^{n} = \frac{EXP(\sum E_A^n \times H_A^n) \times N_{MH}^n}{EXP(\sum E_A^n \times H_A^n) \times N_{MH}^n + EXP(\sum E_A^n \times C_A^n) \times N_{MC}^n} \tag{8}$$

Current Year: Majority. The market share for the current year (at iteration n) HEV purchases by majority buyers and adjusted according to make/model/powertrain availability is given by equation 9.

$$S_{HM}^{n} = \frac{EXP(\sum M_A^n \times H_A^n) \times N_{MH}^n}{EXP(\sum M_A^n \times H_A^n) \times N_{MH}^n + EXP(\sum M_A^n \times C_A^n) \times N_{MC}^n} \tag{9}$$

Current Year: Full Market. The market share for the current year (at iteration n) HEV purchases by combined early and majority buyers and adjusted according to make/model/powertrain availability is given by equation 10.

$$S_H^n = P_E \times S_{HE}^n + (1 - P_E) \times S_{HM}^n \tag{10}$$

7.4 RATE OF DECLINE OF COST WITH TIME AND MINIMUM INCREMENTAL COST

This report's primary purpose is to examine preference coefficients. At this time, there is no production model to address the decline in advanced vehicle cost as a function of time since introduction and/or production volume. Vehicle price and other attribute paths are specified exogenously to the model.

Available estimates to date suggest that the incremental cost for hybrids (Plotkin et al. 2001; Graham et al. 2001; Duvall et al. 2002) will be over $3,000. Table 6 implies that if this is true, market share should be limited to less than 30%, if fuel savings are the only attribute valued by customers. However, if these estimates are too pessimistic and a further decrease to $2,000 is possible, then that share could easily double. Of course, Table 6 is based on a gasoline cost of $1.50/gallon, so another hypothetical way to double the estimated share would be to have gasoline prices rise by 50%, to $2.25/gallon. Table 6 provides a rough reality check on eventual estimates.

Another variable to be determined is the rate at which gas prices will fall. This variable seems to have been determined already, if Toyota is pricing its hybrids on the basis of long-term expectations. Earlier estimates indicated that Toyota is pricing the 2004 Prius at about $3,000 more than a hypothetical competitor. The technical success of the Prius exceeds expectations of prior studies, so reevaluations may lead to conclusions that incremental cost can be lower than $3,000 for a mid-size car. The fuel savings for the 2004 Prius are not estimated to be one-half, however, so the data on the Prius in Table 6 are optimistic compared with data gathered on hybrids produced to date.

In the cases initially tested in the model for this report, hybrid prices are projected to decline steadily from introduction in 2001 through 2015 (Figure 9). A classic example of price reduction in the automotive sector is that for the Model T Ford. We collected data on the "Touring" version of the Model T, from Naul (1978) and Giboney (undated), and converted these prices to year 2000 dollars by using the consumer price index. The results are plotted in Figure 13. A curve is fitted to the real prices (X in the equation is years, starting with 1 in 1908). The plot shows that the Model T had a production life of 18 years and reached its lowest price after about 15 years, after which the real price was relatively constant. So, a 15-year period for the decline to minimum incremental price, as done in our initial test of the model, is "historically" reasonable, although one would expect that it would be possible to do better in modern times. The production volume for the Model T in 1923 was about 1.8 million vehicles, which is far higher than that for hybrids to date. Note, however, that the 1917 real price level was 86% of the eventual total decline, at a production volume of about 0.7 million. Thus, in a span of about nine years, the real price had dropped by 86% of its total 81% decline (i.e., 70%). Later versions of the model are expected to incorporate simple endogenous production cost decline models, so that the linear shape of the price decline profile of Figure 9 will have a curved profile, such as that for the Ford Model T.

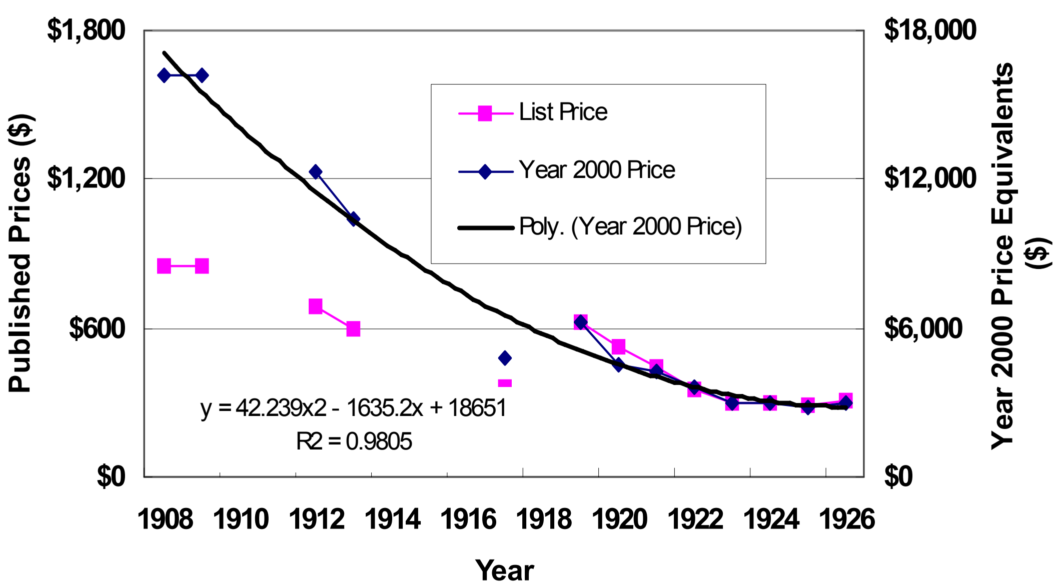

FIGURE 13 Model T Price History

8 IMPLICATIONS AND MODEL RUN EXAMPLES

Figures 14–17 illustrate some of the intended model behavior. These results are for the first vehicle model programmed into an initial test version of the modeling approach. The behavior of a final model may vary in detail, but it should not vary in terms of general attributes illustrated in these figures. The example provided is for competing hybrid electric and conventional powertrains in a small car and assumes a fuel price of $1.50/gallon. Figure 9 showed the exogenous assumptions about the relative behavior of the hybrid powertrain. The only relative improvements simulated over time are hybrid price and reductions in fuel consumption. The range of the hybrid is consistently greater than that for a conventional vehicle, while top speed and luggage space are consistently lower. Acceleration remains the same. The data for the hybrid imply that a hybrid powertrain can, by 2015, allow a 75% increase of fuel economy at an incremental cost of about 7% of the conventional vehicle's cost.

As illustrated in the text that discusses the Ford Model T (Section 7.4), the shape of a price-reduction curve with increasing production volume and years of production experience involves relatively rapid early declines, followed by reduced rates of improvement in later years, until improvement finally stops. Another feature of the plot in Figure 9 is that it shows a continuous decline, while the real pattern in practice is likely to involve a series of relatively discrete steps, as different versions of the technology are sequentially introduced. AVID at this time does not include a price decline model as a function of production volume and years of experience, although we recognize this deficiency and address it in this report (in Section 7.4). The shapes of the two exogenously specified attribute improvements in Figure 9 are thus admittedly stylized. However, their joint discrete end in 2015 is useful in subsequent graphs to help conceptually illustrate when one important phase of the technology introduction sequence has been completed. The resulting 2015 "kink" in market share curves shows up in several graphs.

In Figure 14, the change of value of attributes as a function of time is illustrated. The model is set up so that users can specify the number of years over which early adopters dominate the early group, and this period is followed by a presumed drop in interest by early adopters. The modeling approach assumes that as early adopters drop out of the market, the appropriate attribute valuations shift toward the type of buyer we call early buyers. For the early group, the user specifies a rate at which preferences decay from early adopter values toward early buyer values. As seen in this illustration, after an exogenously specified six years after year 2000 market introduction of the new hybrid powertrain technology, the early group exhibits a sharp decline in its willingness to pay more for fuel economy (reduced fuel consumption), acceleration (reduced 0–60-mph time), and top speed.

Figure 15 illustrates the interactive effects of overall preferences for the new technology as it is made available in the market and evolves technologically over time. In Stage 1, the early adopters are far more interested in purchasing the new powertrain technology in the first six years after introduction, but interest after six years is simulated to drop rapidly. From initial introduction to year six, the propensity to buy actually expands because early group coefficients

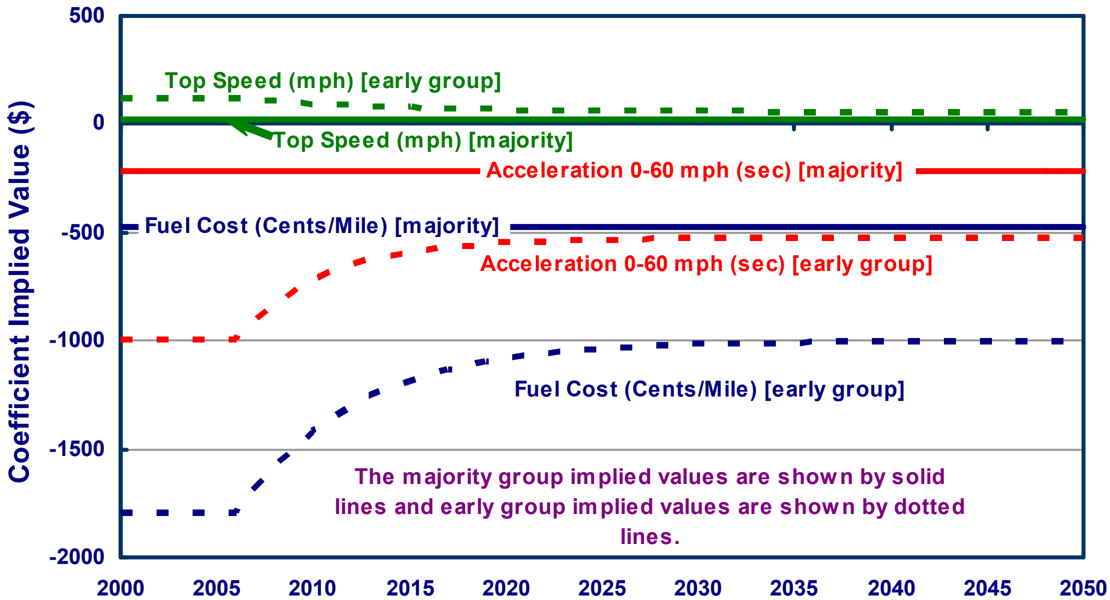

FIGURE 14 Evolving Dollar Values of Attributes as a Function of Time

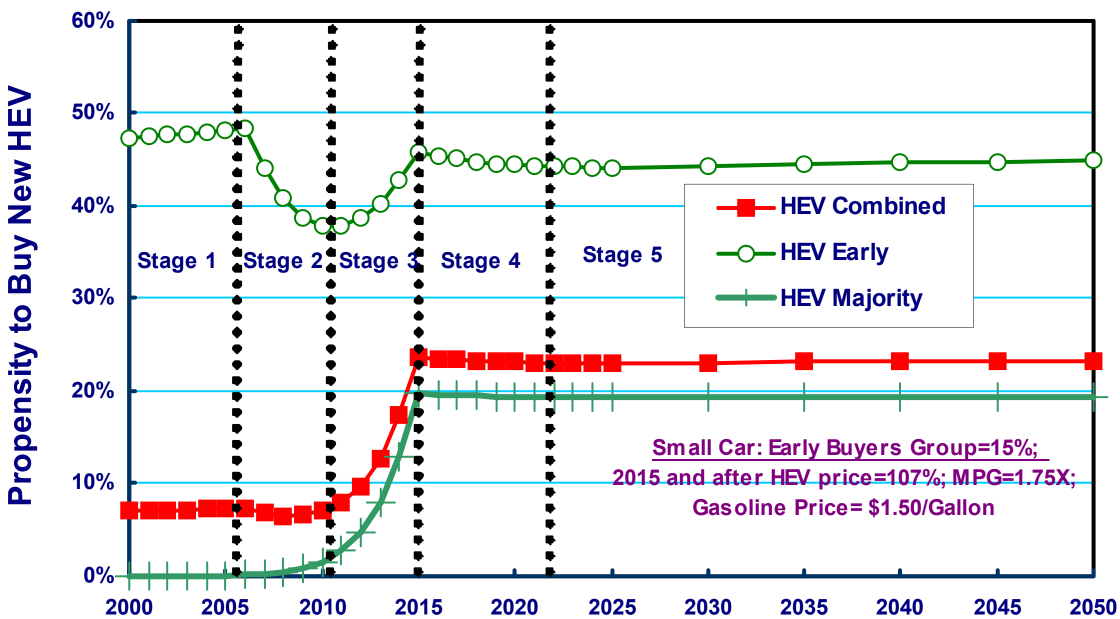

FIGURE 15 Share of Customers Willing to Buy if Enough Cars with Specified Attributes Were Available

are held constant while the vehicle attributes improve. Note that the improvement in vehicle attributes in the first six years draws a mere 0.2% of the majority buyer group into the potential market. In Stage 2, for the years 2007 and 2008, the total potential market actually shrinks as the exit of early adopters causes the early group share to drop more rapidly than the majority group increases. From 2006 to 2010, the exit of early adopters is simulated to cause the total early group share to shrink, despite consistent improvements in the technology. However, in Stage 3, from 2011 to 2015, the rate of decline of early group attribute valuations is less rapid than the effect of improvement in the technology, and the early group share is simulated to rise. After 2015, in Stage 4, the positive effect of vehicle attribute improvements stops. The early group's willingness to pay for the superior attributes of the technologies continues to decline slowly after this, so that the propensity of the early group to buy is simulated to decline slightly through 2022. After 2022, in Stage 5, the propensity to buy an HEV powertrain remains stable.

The importance of the early group (and its proper simulation) to the ultimate success of the technology is illustrated by the estimate that the early group represents over 95% of the potential market through 2007 and over 50% through 2012. In the long run, the simulation implies that recognition of the early group in the model only raises the potential market size from 19% to 23%. Nevertheless, without the early group's high propensity to buy (and thereby creating an incentive to get the technology started), it might not be introduced.

Figure 15 illustrates the preliminary AVID model estimate of what share of hybrids *could be* sold, given the specified technical attributes and history of availability. However, it is not an estimate of how many are actually sold. A producer introduction model is combined with the estimate of potential market in order to create an estimate of actual sales of the vehicles. The combined effects of the consumer preferences model and the producer response model are illustrated in Figure 16. Despite the marked fluctuations in aggregate consumer propensity to buy in the potential market during the fist decade and a half, the modeled delays of producers in reacting to this emerging potential market cause the actual market result to be a relatively smooth prediction for share of the new vehicle market represented by hybrid vehicle production. Such a pattern of technology introduction is common in history. The classic example of a manufacturer delaying introduction despite emerging consumer propensity to buy more advanced technology is the continued production of the Model T Ford in the 1920s as GM replaced Ford as the number-one manufacturer.

Although it is not explicit, the model implies that the share of the market attained by the first producers to sell the technology will expand, while for producers that delay or refuse the production of the technology, market share will shrink. However, the model also implies that success is not guaranteed if the path of improvement of attributes (or fuel price) is uncertain.

Figure 17 illustrates more clearly the total market paths over time. Once the technology attributes have been simulated to have stabilized, and the initial spurt of interest from early adopters and early buyers has been superseded and overwhelmed by the majority buyer market, the actual number of vehicles produced converges to a relatively stable share of the market, representing fulfillment of the potential of the technology.

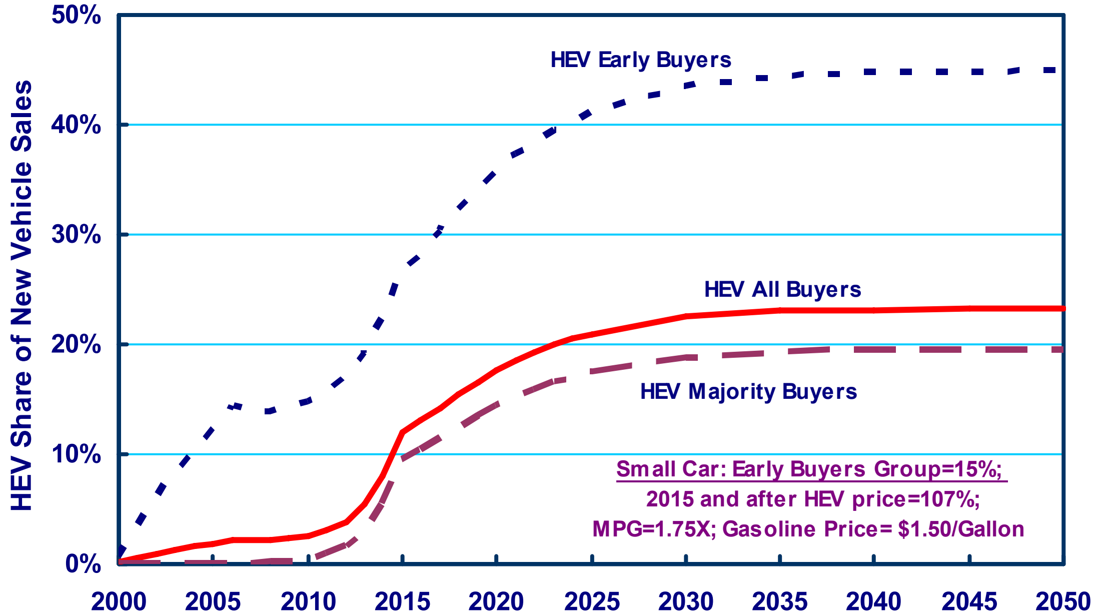

FIGURE 16 Share of New Car Market Held by HEVs, Given Vehicle Production Decisions

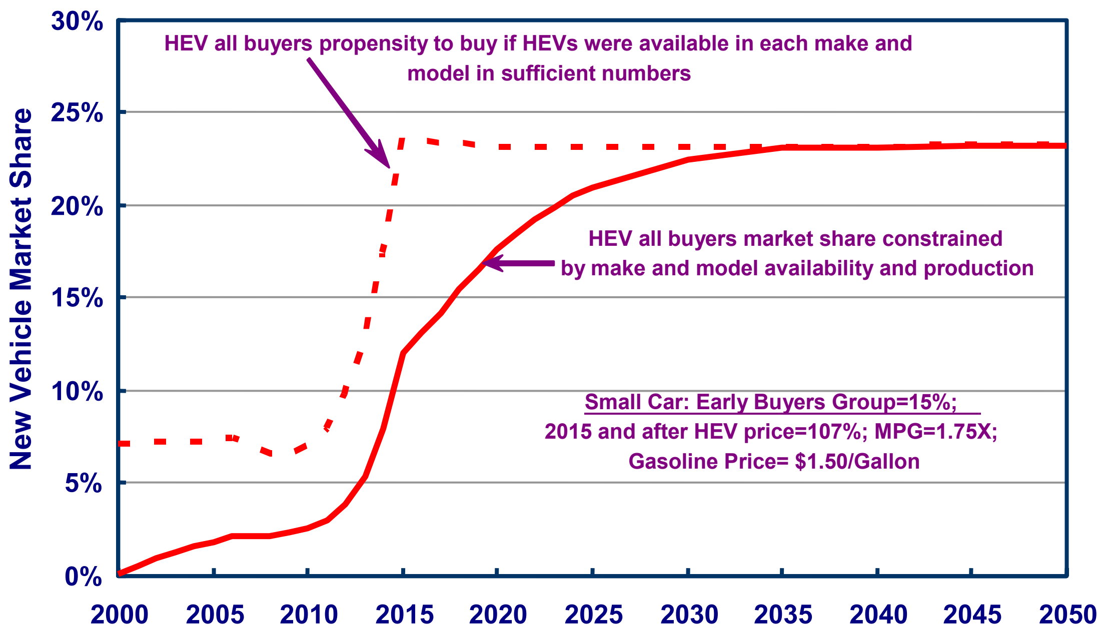

FIGURE 17 Potential (Unconstrained) vs. Actual Share of Total Small Car Market Held by HEVs

Note that the relatively smooth growth path for hybrids could be altered if gasoline prices fluctuated. The simulations illustrated here are based on constant fuel prices of $1.50/gallon. One reason for incorporating producer delays into the model is that the effects of rapid and/or dramatic fluctuations in fuel prices on model predictions need to be moderated. The reality is that producers cannot and do not quickly react to dramatic, potentially reversible changes in consumer preference that are associated with rapid changes in fuel price, which are uncertain. One effect of the lag structure in the producer decisions model would be to require fuel prices to remain elevated for several years before production plans would be significantly altered. Eventually, according to the AVID structure, producers "catch up" and match their production levels to the propensity of consumers to buy, and a stable market share is achieved.

This simulation implies that majority buyer interest would "take over" between 2010 and 2015, before the simulated technological improvements have stabilized in 2015. On the basis of this simulation, it appears that majority buyers begin to be interested when the technology achieves the degree of success shown in about 2010. The technological improvements (reduced price and fuel consumption) from 2010 to 2015 are simulated to make a great deal of difference to majority buyers and to lead to fairly significant, but not sweeping, market success.

The example shown in Figures 9 and 14–17 of how the model works is, of course, for a specific set of circumstances. A criticism of stated-preference models was that they were too sensitive to fuel price and too insensitive to vehicle price. In the long run, this model and these initial test-input assumptions, like NEMS, do simulate a population of customers who are predominantly sensitive to vehicle price and not sensitive to fuel price. This phenomenon is shown in Figure 18, in which the effects of a series of vehicle price and fuel price experiments are illustrated. Aside from the constant-gasoline-price scenario in Figures 5–17, a high-gasoline-price scenario is simulated. The gasoline price is slowly increased to $3.00 by 2008. Also, the HEV price increment over the CV is tested at 18% by 2015 instead of 7%.

Simulations were carried out for the two gasoline-price- and HEV-price-increment scenarios. If the price increment for the hybrid vehicle does not drop from 18% to 7%, and if gasoline prices fall to $1.50 per gallon (similar to the 1960s and mid-1990s), then HEV sales are predicted to shrink to perhaps 1% from a peak of about 3% reached within a few years. In contrast, holding the hybrid vehicle cost increment constant at 7%, the per-gallon price of gasoline would have to double from $1.50 to $3.00 to achieve an increase in share to about 57%. Investigation of the historical rate of transition to FWD from about 1979 to 1988 (see Section 7.3.1) as a logical analogy suggests that the model's prediction of share may be a bit too responsive to gasoline price. Nevertheless, the present focus of the model is on small cars, not the entire car market. In fact, penetration of front-wheel drive in small cars was more rapid.

Note that the lowest cost (retail price) increment for a hybrid powertrain that has been estimated and published with the participation of the authors of this report is 12% for a "low-drag, reduced-mass" mid-size car (Graham et al. 2001). This vehicle — which is similar in several respects to the 2004 Toyota Prius — was also simulated to have an increase in fuel economy of 80%, so it was comparable to the cases simulated here, the increase in fuel economy of which is 75%. However, since that estimate, the 2004 Prius has demonstrated component

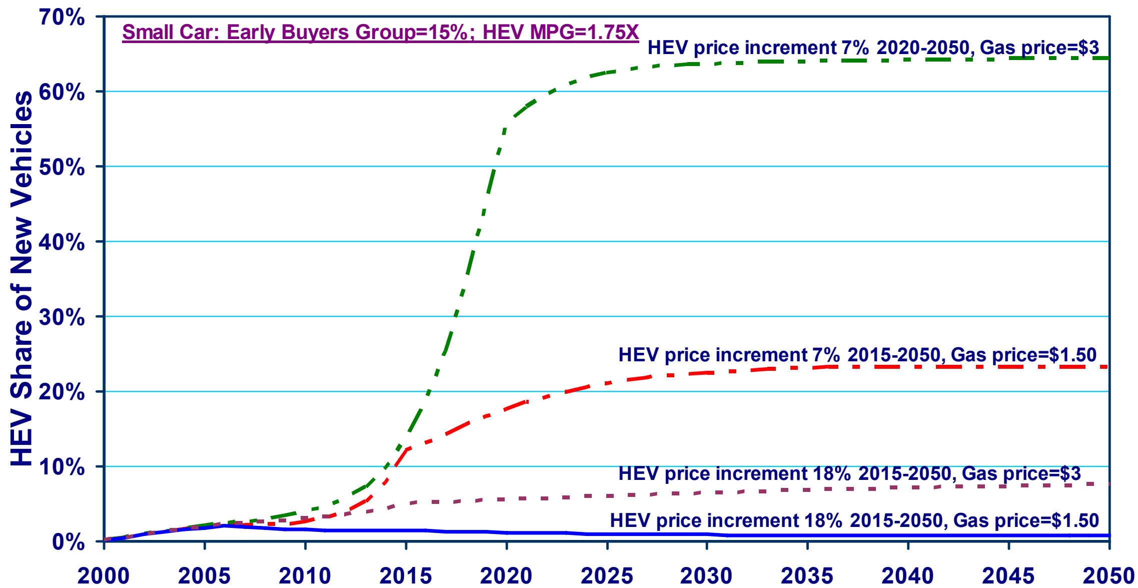

FIGURE 18 HEV Market Share Predictions from Tests of the Interim AVID Model

attributes that may lead to even lower costs than estimated in that study. Further, versions of hybrids to be introduced in 2005 will have four-wheel drive, for which the hybrid technology appears to be cost-effective (EEA 2002). Thus, we suggest that an incremental cost of less than 12%, in conjunction with an increase in fuel economy of about 75%, may be possible in the next few years for hybrid configurations in some small and mid-size car platforms, although the 7% base case used here seems to be optimistic at this time.

On the basis of the exercise illustrated in Figure 18 and the comments in the previous paragraph, the long-term potential of the hybrid vehicle powertrain is promising, although uncertain. Vehicle price increment and future gasoline prices seem to be key factors, the values of which could cause a wide range of eventual long-term market shares for hybrid powertrain technology. It does appear that early buyers and higher-than-expected oil prices have prompted several automakers to produce hybrid powertrains to further test consumer response and the ability of automakers to refine the technology.

We do not believe that the model should be any more responsive than illustrated here and, in its ultimate form, should probably be less responsive than shown for the $3.00/gallon gasoline price cases. In that case, the market share for HEVs rises from 10% to 80% in five years, which is far faster than the rise in market share for FWD vehicles in the 1970s, which took 10 years to rise from 10% to 80%. We did note, though, that this case is for estimated small car preferences, not all car preferences. Also, both fuel economy and gasoline price increases are greater than those for the FWD example.

Leiby and Rubin (2003) have also estimated that extremely rapid rates of change are possible — in their case, with subsidies. They estimated that the market could jump from zero to over 70% within two years given a $2,400-per-vehicle subsidy. They estimated that, with the removal of the assumed subsidy, hybrids would remain in the market, but they would decline in share to about 28% after 16 years (not far from our base estimate). Adoption of FWD in automobiles in the United States took about 10 years, even under the pressures of a fuel economy regulation (Figure 12) and temporarily high gasoline prices (not far from $3.00 in today's dollars). Thus, our opinion is that the producer decisions sub-model may be too responsive to gasoline prices in the absence of regulation, even though it does tend to delay and damp simulation of extremely rapid and abrupt shifts in market share.

An important contrast between this model and that of Leiby and Rubin is the baseline "no subsidy" projection. Because of early group preferences, our simulation implies that hybrids would obtain a small, but significant, share of the market — even in the absence of a subsidy (although we must concede that those hybrids now in the market have actually benefited from subsidies, so it would not be possible to prove the validity of this simulation result). Our projections of hybrid attributes (particularly cost and fuel economy differentials) may, however, be somewhat optimistic and are probably optimistic relative to estimates used by Leiby and Rubin (2003).

Short-run model behavior. The early market penetration values associated with Figure 18 are shown in Figure 19. Actual sales of hybrids through 2004 are also illustrated in Figure 20. To date, sales of the Civic and Prius have been within the EPA's compact-car category through 2003. In late 2003, there was a model change for the Prius that led the EPA to classify the new 2004-model-year Prius as a mid-size passenger car. The new model was vastly superior to the 2003 Prius — it was larger and more fuel efficient, offered faster acceleration, and listed for the same price as the 2003 model. In terms of interior volume, the new Toyota Prius was between Toyota's compact Corolla and mid-size Camry. In Figure 18, the plot is constructed as if the 2004 Prius is a small car.

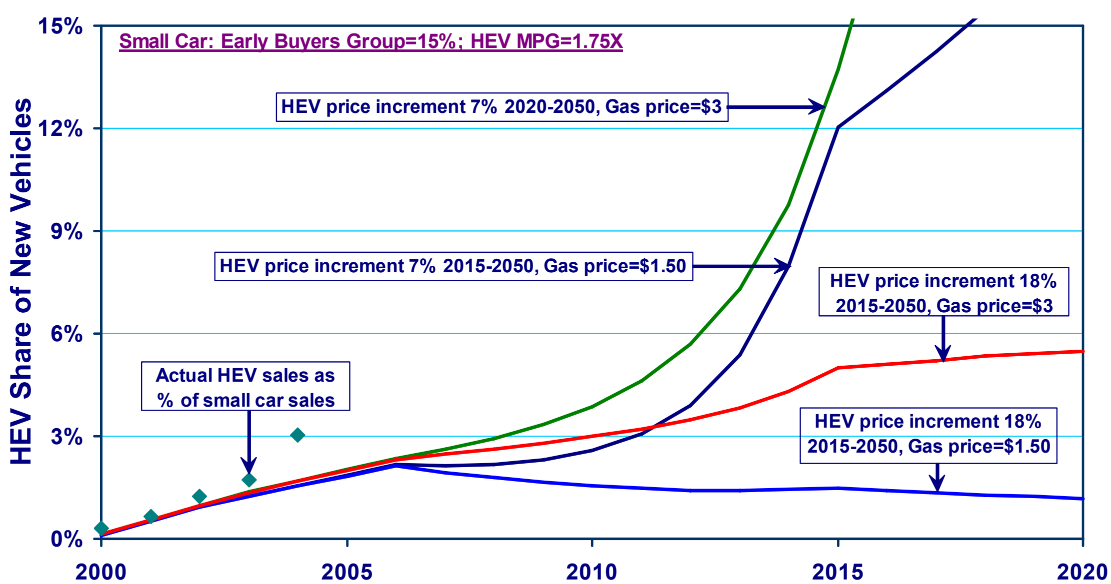

FIGURE 19 HEV Market Share Predictions to 2020

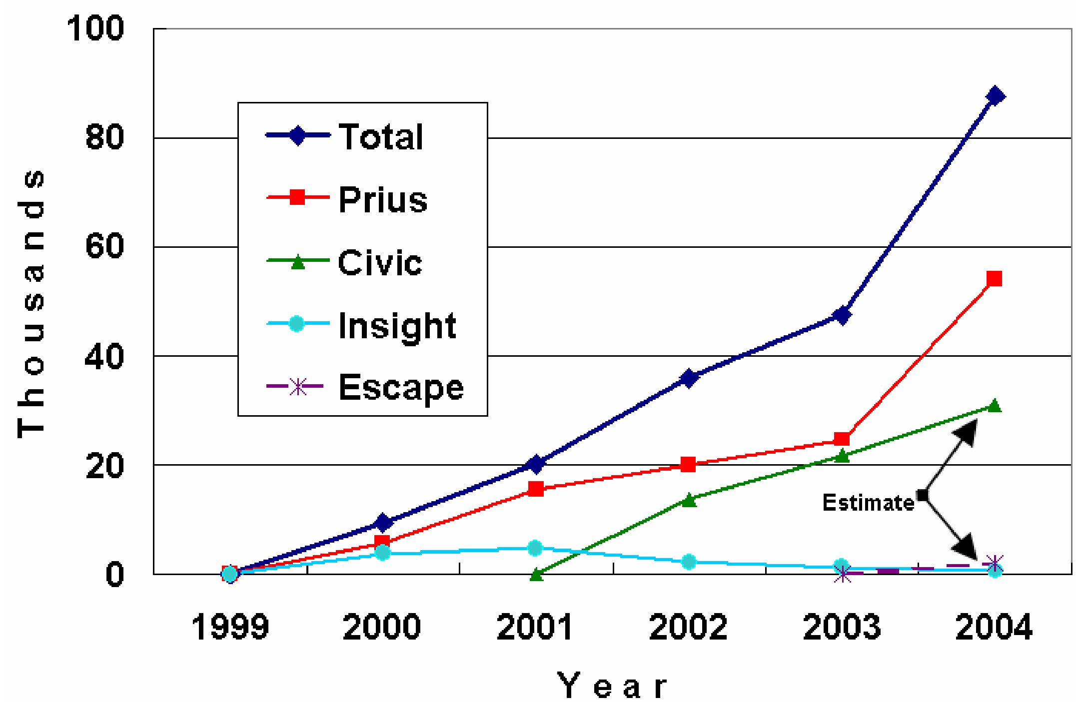

FIGURE 20 U.S. HEV Sales History, 1999–2004

The model structure applied in Figures 18 and 19 was implemented in summer of 2004, before the study review. Thus, the model has not been "calibrated" to 2004 sales at this time; however, comparison of its predictions to actual 2004 sales is legitimate. In terms of the model structure, two major events occurred in 2004 to cause a discrete increase in HEV sales:

1. Toyota switched from a production facility capable of producing 30,000 Prius hybrids to one capable of producing 120,000. Thus, on the producer-decisions side, experience with the earlier Prius model and consumer response led to a decision to expand production.

2. There was a discrete jump in the technical capabilities of the new model of Prius. The simulation done here does not include a discrete jump in technical capabilities of hybrids in 2004 (Figure 9).

We have said that coefficients similar to those recommended by Greene and Chin — when incorporated into this model — would not have led to a prediction of any market share for hybrid vehicles, at least with the attributes of hybrids as entered in the simulations here.

Although the comparison is not based on standardized inputs, the pattern of HEV market penetration predicted by AVID can be compared to the predictions of the 2004 AEO, which is shown in Figure 21.

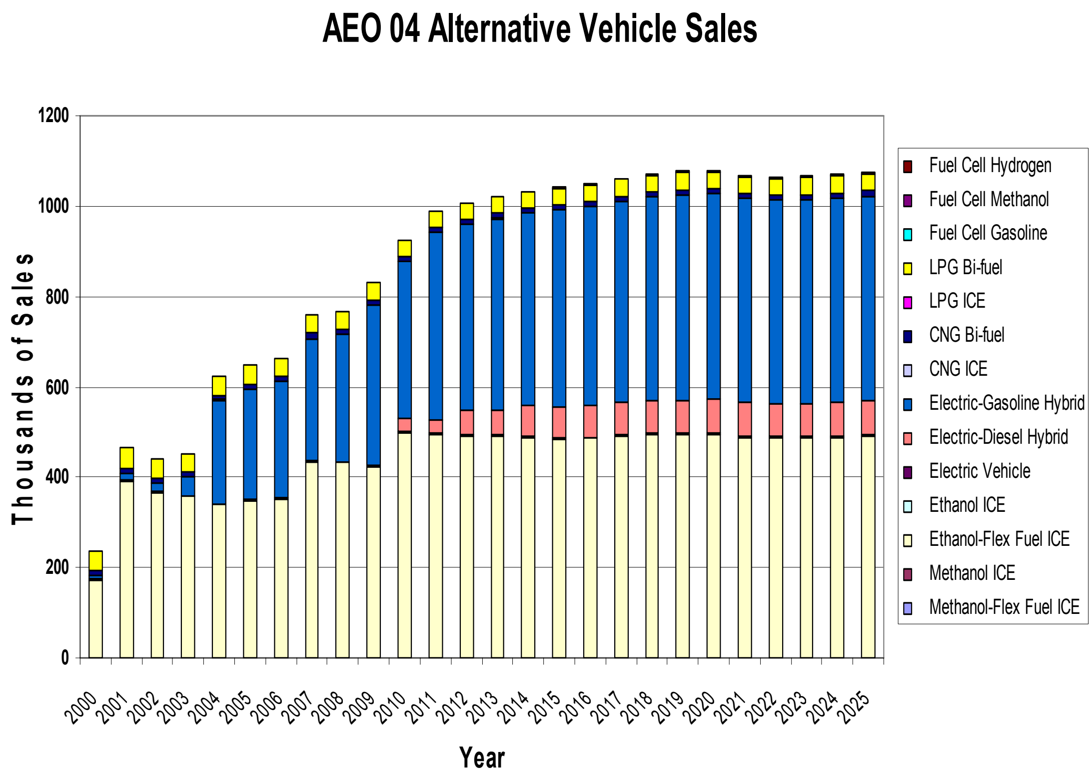

FIGURE 21 2004 Annual Energy Outlook Hybrid Sales Projections

Without studying the details of the AEO NEMS forecasting inputs, one cannot know the cause of the pattern shown. Relative to actual historical hybrid sales totals for 2000–2003, the 2004 AEO "projections" shown in Figure 21 are somewhat low. However, projections for hybrids for the same years in the 2001 AEO were high, amounting to 75,000 in 2000, 65,000 in 2001 and 2002, and jumping to 470,000 in 2003. The 2004 AEO predictions shown in Figure 21 are more modest, but they also jump sharply in 2004, to a value of over 200,000, which is more than twice actual 2004 sales. Share stability of slightly more than 400,000 is predicted between 2010 and 2020. The 2001 AEO predicted a similar jump in HEV sales in 2003 rather than in 2004. In fact, many of the earlier announcements by automakers about the introduction of hybrids have proven to be optimistic. The models were either not introduced at the times indicated, or the levels of production and sales (in pickup trucks, in particular) were quite limited.

An examination of the fuel economy increases assumed for gasoline hybrids in the 2001 AEO indicates about a 37% increase in 2004, but the increase falls to 27% in 2013. The 2004 AEO reports a discrete drop in the increase in fuel economy from 54% in 2003 to 41% in 2004, with a further drop to 31% by 2013. Because hybrid trucks introduced to date achieve an increase in fuel economy of only about 10%, an estimate of a drop in HEV mpg gain for all LDV hybrids once hybrid trucks enter the market is very plausible. The test case simulated here for cars only assumes an increase in fuel economy of 50% in 2003, rising to 75% in 2015.

The long-term 2004 AEO projection for hybrid sales represents about 2% of a 20-million-vehicle market. Only the most pessimistic case simulated here is consistent with this prediction, but the gains in fuel economy significantly exceed those assumed by EIA. With these caveats in mind, we note that with a 12% HEV price increment, which is consistent with the price increment predicted by studies in which we have participated (Plotkin et al. 2001; Graham et al. 2001), would clearly lead to a significantly larger share of the market than that predicted by the EIA's 2004 Annual Energy Outlook. An important difference between the interim AVID model, as set up, and the NEMS is that the early group preferences remain considerably more favorable for the HEV technology once market shares have stabilized. As a result of including the separate early group simulation representing an estimated 15% of new LDV buyers, the model is probably inherently more favorable to HEV market penetration than the NEMS used to generate AEO predictions. However, as noted, the gains in fuel efficiency by passenger car hybrids assumed here is more optimistic than that for all LDVs used in NEMS, which also contributes to the implication of greater success for hybrids.

9 CONCLUSIONS

Some key features of the suggested model are described below.

- Expectations of vehicle producers — developed theoretically through an analysis of stated-preference information about candidate new technologies — are the basis for vehicle introduction. The adapted data become the basis of an expectation of marketability, which is followed by an attempt to capture a portion of the potential market. The model is programmed in such a way that actual production and sales during the introductory phase lag the potential market. The potential market is a measure of consumer propensity to buy if an adequate number of vehicles were available with projected vehicle attributes.

- The estimate by vehicle producers of the potential market is a function of the attributes of the technology that they believe they are able to produce. As the market expands and the technology evolves (improves), the estimates of the potential market expand and intentions to produce increase. Once the technology "plateaus," then potential share stabilizes, and actual production is simulated to catch up and match it. The model can, in certain circumstances, predict initial success with early adopters, followed by a shrinking share as early adopters become satiated and early buyers begin to dominate. In effect, the rate at which attributes improve with experience and production volume has to be sufficiently rapid to capture early buyers, after early adopters, or the share can actually drop back to zero. The rotary engine introduced decades ago by Mazda is an example of a powertrain technology that went through such a sequence of events. "Displacement on demand," which is now reentering the market, also failed after initial introduction and testing by high-income customers of Cadillac over two decades ago. However, we concede that oil price shifts also had an effect on the failure of these two technologies, not just differences between early adopter and early buyer preferences. Further, in the example herein, it is shown that improvement in the technology is a critical factor in moving from early adopters to the majority of the market. In the case of Cadillac's V8/6/4, it proved unreliable, and this problem was not solved. Thus, early adopters probably did not recommend the technology to early buyers.

- As total market share increases over time, the early group/low-market-share coefficients move toward the majority buyer/high-market-share coefficients moderately rapidly and then become relatively stable. Stability is reached after coefficient values have converged by a user-specified fraction of the initial difference between early adopter and majority buyer coefficient values[3].

---

[3] As a result of the changing coefficients, vehicle attributes must improve at a rate that overcomes a tendency toward market shrinkage as early adopters lose interest in the formerly unusual attributes of a technology, if market success with the majority is to be achieved.

- At low market share, the early group in AVID is characterized to be far less sensitive to vehicle price than the buyers in the EIA's NEMS. This price sensitivity initially reflects the willingness of early adopters to buy unique vehicles at a high price premium and subsequently reflects the higher average income and annual driving of early buyers.

- In the Greene and Chin model, the fuel-cost coefficient is based on the logic that a buyer could not possibly be willing to pay more for fuel savings than the dollars saved per vehicle for an average amount of vehicle travel per year. However, the suggested coefficients for the important minority early group within the new model are based on the idea that (1) most of the earliest buyers purchase a high-efficiency vehicle for a combination of altruism and "bragging rights" and (2) others later place a higher value on fuel cost and other key vehicle attributes because they drive far more than the average buyer. In particular, this yields a much higher early, low-market-share value ($1,800) (attributed to a fuels savings of one cent per mile) than the Greene and Chin formulation ($475).

- At low market shares, the new model also places a higher value on vehicle performance than does the Greene and Chin model. For example, acceleration for the early group is initially assigned a value 5 times as high as that for the majority group, but it eventually drops toward the Greene and Chin value.

- The modeling approach proposed offers a richer description of consumer behavior during the introduction of a new transportation technology than does the approach it is intended to replace. Because of this richness, users must make many judgments in implementing this new approach. Many of those judgments could be refined or revised as a result of future research that should be done, if this approach seems logically plausible.

- One question raised by the model approach is whether a successful technology *must* first succeed with early adopters. Do these buyers act as leaders and risk takers who "shake out" the new technology and assure its quality and economic desirability for the more risk-averse buyers who follow?

- Although much of this study is generic in its implications, we have dedicated specific effort to developing coefficients appropriate for HEVs. We include new variables that allow market share to be affected by such characteristics as the right to use an HOV lane (presently granted to hybrids in the Washington, D.C., area) and the ability to provide backup power for a house (a potential future feature).

10 REFERENCES

Annual Energy Outlook: AEO

AEO, 2001, *Annual Energy Outlook 2001 With Projections to 2020,* Department of Energy, Energy Information Administration Report DOE/EIA-0383 (2001), Washington, D.C.

AEO, 2003, *Annual Energy Outlook 2003 With Projections to 2025,* Department of Energy, Energy Information Administration Report DOE/EIA-0383 (2003), Washington, D.C.

AEO, 2004, *Annual Energy Outlook 2004 With Projections to 2025,* Department of Energy, Energy Information Administration Report DOE/EIA-0383 (2004), Washington, D.C.

Bass, F.M., 1980, "The Relationship between Diffusion Rates, Experience Curves, and Demand Elasticities for Consumer Durable Technological Innovations," *Journal of Business* 53(3):S51–S67.

Brownstone, D., D.S. Bunch, and T.F. Golob, 1994, *A Demand Forecasting System for Clean-Fuels Vehicles,* Institute of Transportation Studies Paper UCI-ITS-WP-94-4, University of California at Irvine, Irvine, Calif.

Bunch, D.S., M. Bradley, T.F. Golob, R. Kitamura, and G.P. Occhiuzzo, 1991, *Demand for Clean-Fuel Personal Vehicles in California: A Discrete-Choice Stated Preference Survey,* Institute of Transportation Studies paper UCI-ITS-WP-91-8, University of California at Irvine, Irvine, Calif. (U.C. Davis Report UCD-ITS-RR-91-14).

CEC: California Energy Commission

CEC-Morpace, 2003, *California Vehicle Survey 2002, Final Report*, Morpace International Market Research and Consulting, Farmington Hills, Mich., Jan. 10.

Consumer Guide (the Auto Editors of), 1990, *Ford: The Complete History,* Publications International Ltd., Lincolnwood, IL. Duvall, M., et al., 2002, *Comparing the Benefits and Impacts of Hybrid Electric Vehicle Options for Compact Sedan and Sport Utility Vehicles,* Final Report No. 1006892, Electric Power Research Institute, Palo Alto, Calif., July.

EEA: Energy and Environmental Analysis, Inc.

EEA, Inc., 2002, *Analysis and Forecast of the Performance and Cost of Conventional and Electric-Hybrid Vehicles,* California Energy Commission Consultant Report P600-02-013CR, March.

EIA: Energy Information Administration

EIA, 2003, *Monthly Energy Review*, U.S. Department of Energy, Energy Information Administration, Washington, D.C., July.

General Motors Corp., et al., 2001, *Well-to-Wheel Energy Use and Greenhouse Gas Emissions of Advanced Fuel/Vehicle Systems — North American Analysis, Executive Summary Report,* [URL http://www.transportation.anl.gov/ at document address http://www.transportation.anl.gov/pdfs/TA/163.pdf], Argonne National Laboratory, Transportation Technology Research and Development Center, Argonne, Ill.

Giboney, J.E. (undated), *Tour Book of the Towe Ford Museum of Californi*a, published by Towe Ford Museum, Sacramento, Calif.

Graham, R., et al., 2001, *Comparing the Benefits and Impacts of Hybrid Electric Vehicle Options,* Final Report 1000349, Electric Power Research Institute, Palo Alto, Calif.

Greene, D.L., 1994, *Alternative Fuels and Vehicle Choice Model,* Oak Ridge National Laboratory Report ORNL/TM-12738, Oak Ridge, Tenn. (October).

Greene, D.L., and S.M. Chin, 2000, *Alternative Fuels and Vehicles (AFV) Model Changes,* Center for Transportation Analysis, Oak Ridge, Tenn. (contract DE-AC05-00OR22725), Nov. 14.

Hausman, J.A., 1979, “Individual Discount Rates and the Purchase and Utilization of Energy-Using Durables,” *Bell Journal of Economics* 10:33–54.

Heim, E., 1999, *Assessment of Current Knowledge of Hybrid Vehicle Characteristics and Impacts,* Report EPRI TR-113201, Electric Power Research Institute, Palo Alto, Calif., Aug.

Heraud, D., 2001, “Reviews,” Microsoft “Carpoint” web site, http://www.carpoint.com/vip/Heraud/ (discontinued).

Hermance, D., 2003, “Marketing Advanced Technology Vehicles,” presented at Conference on The Hydrogen Transition, held at the Asilomar Conference Center, Asilomar, Calif., July 29–Aug. 1.

Kavalec, C., 1999, “Vehicle Choice in an Aging Population: Some Insights from a Stated Preference Survey for California,” *The Energy Journal* 20(3):123–138.

Kurani, K.S., T. Turrentine, and D. Sperling, 1994, “Demand for Electric Vehicles in Hybrid Households: An Exploratory Analysis,” *Transport Policy* 1(4):244–256.

Kurani, K.S., T. Turrentine, and D. Sperling, 1996, “Testing Electric Vehicle Demand In ‘Hybrid Households’ Using A Reflexive Survey,” *Transportation Research D* 1(2):131–150.

Kurani, K.S., T. Turrentine, R. Heffner, and B. Williams, 2004, "How do Car and Truck Buyers Think about Fuel Economy? An Interim Report," presented to the Energy Committee of the Transportation Research Board, Washington, D.C., Jan. 14.

Kurani, K.S., and T. Turrentine, 2004, *Automobile Buyer Decisions about Fuel Economy and Fuel Efficiency*, ITS-RR-04-31, University of California Institute of Transportation Studies Report, Sept. 1.

Leiby, P., and J. Rubin, 2003, "Transition Modeling of AFVs and Hybrids: Lessons Learned," presented at Asilomar Conference, Pacific Grove, Calif., July 29–Aug. 1.

Malesh, T., 2000, *A Hybrid-Electric Sports Car for Every Garage?* Power Report, J.D. Power and Associates, Agura Hills, Calif.

Moore, G.A., 2002, *Crossing the Chasm: Marketing and Selling Disruptive Products to Mainstream Consumers,* revised edition, HarperCollins, New York, NY.

Morpace International Market Research and Consulting, 2003, *California Vehicle Survey 2002. Final Report*, Farmington Hills, Mich., Jan. 10.

Naul, G.M., ed., 1978, *The Specification Book for U.S. Cars 1920–29,* Motorbooks International, Osceola, Wis.

Naul, G.M., ed., 1980, *The Specification Book for U.S. Cars 1930–69,* Motorbooks International, Osceola, Wis.

Nichols, R.J., 2003, The Methanol Story: A Sustainable Fuel for the Future, *Journal of Scientific & Industrial Research* 62:97–105.

ORC: Opinion Research Corporation

ORC International, 1996 and 1997, CARAVAN Services, Surveys of 1000 Households during Oct. 17, 1996, and Oct. 24, 1997, for National Renewable Energy Laboratory, Golden, Colo.

ORC International, 1998, 1999, and 2001, CARAVAN Services, Surveys of 1000 Households during Feb. 19, 1998; Aug. 5, 1999; and Nov. 2, 2001, for National Renewable Energy Laboratory, Golden, Colo.

ORC International, 2003, CARAVAN Services, Survey of 1000 Households during March 15–16, 2003, for National Renewable Energy Laboratory, Golden, Colo.

Popely, J., and J. Mateja, 2004, "Green Fades as Hybrids Push Horsepower," *Chicago Tribune,* Business Section, p. 1 and 10, Jan. 18.

Power, J.D., and Associates, 2001, *Sales Report December 2000: Monthly Analysis of Sales in the U.S. Light-Vehicle Market,* Agoura Hills, Calif.

Plotkin, S., D. Santini, A. Vyas, J.L. Anderson, M. Wang, J. He, and D. Bharathan, 2001, *Hybrid Electric Vehicle Technology Assessment: Methodology, Analytical Issues, and Interim Results,* ANL/ESD/02-2, Argonne National Laboratory, Oct.

Poyer, D., and D. Santini, 1999, “The Value of Range: The Market Penetration of Alternative Fuel Vehicles,” presented at the 78th Annual Meeting of the Transportation Research Board, Washington, D.C., Jan. 11.

Rogers, E.M., and F.F. Shoemaker, 1971, *Communication of Innovations: A Cross-Cultural Approach,* Free Press, New York, NY.

Santini, D.J., and A. Vyas, 2003, “Sensitivity of the AVCM Model to Plausible Changes in Input Variables,” draft memo to Phil Patterson, U.S. Department of Energy, June 18.

Santini, D.J., and A. Vyas, 2005, “Influence of Hybrid and Diesel Vehicle Introduction in the Technology Adoption Life Cycle,” paper number 05-2434, presented at 84th Annual Meeting of the Transportation Research Board, Washington, D.C., Jan. 9–13.

Santini, D., P. Patterson, and A.D. Vyas, 2000, “Importance of Vehicle Costs, Fuel Prices, and Fuel Efficiency in Hybrid Electric Vehicle Market Success,” *Transportation Research Record* 1738:11–19.

Santini, D.J., 1989, “Interactions among Transportation Fuel Substitution, Vehicle Quantity Growth, and National Economic Growth,” *Transportation Research A* 23(3):183–207.

Smith, B., 2004, Center for Automotive Research, Ann Arbor, MI, personal communication D. Santini, Argonne National Laboratory, Argonne, Ill., July 20.

Taylor, D., and A. Miller 2003, *Collaborative Study on the Market Potential for Plug-in HEVs and Engine Dominant HEVs in 2010 by EPRI, Automakers, Agencies, Utilities, National Labs, and Others: A Description of the Customers Who Prefer HEVs*, Proceedings of the 20th International Electric Vehicle Symposium and Exposition, EVS-20 Powering Sustainable Transportation, Held at Long Beach, Calif., November 15–19.

Tompkins, M., D. Bunch, D. Santini, M. Bradley, A. Vyas, and D. Poyer, 1998, “Determinants of Alternative Fuel Vehicle Choice in the Continental United States,” *Transportation Research Record* 1641:130–138.

Toyota Motor Corporation, Public Affairs Division, 2003, “Hybrid Synergy Drive: Toyota Hybrid System THS II” [URL www.toyota.co.jp], Tokyo, Japan, May.

Turrentine, T., and K. Kurani, 2005, “Automotive Fuel Economy in the Purchase and Use Decisions of Households,” in Proceedings of the 84th Annual Meeting of the Transportation Research Board, Washington, D.C., Jan.

U.S. Census Bureau, 2000, *Statistical Abstract of the United States,* Department of Commerce, Washington, D.C.

U.S. Department of Transportation, Federal Highway Administration, 1997, *Our Nation's Travel: 1995 NPTS Early Results Report,* Publication No. FHWA-PL-97-028, Sept.

Wall Street Journal (WSJ), 2004, "Cars: Hybrid Vehicles Gain Popularity Among Americans," April 22.

Wang, M., K. Stork, A. Vyas, M. Mintz, M. Singh, and L. Johnson, 1997, *Assessment of PNGV Fuels Infrastructure. Phase I Report: Additional Capital Needs and Fuel-Cycle Energy and Emissions Impacts,* ANL/ESD/TM-140, Argonne National Laboratory, Argonne, Ill.

APPENDIX A: RESPONSES TO REVIEWS: RELATIONSHIPS TO LITERATURE ON INNOVATION DIFFUSION AND RESULTS OF A SURVEY ON HEV AND DIESEL PREFERENCES

A.1 OVERVIEW

We examine Moore's (2002) qualitative concept of a potential "chasm" in share growth after early adopters have been served and early buyers begin to dominate the market. We also examine a survey of quantitative innovation diffusion literature by Mahajan and Peterson (1985) and illustrate how many of the conceptual approaches adopted in the Advanced Vehicles Introduction Decisions (AVID) model have been posited and studied by other researchers, although they seldom examined transportation technology innovation. The quantitative literature up to 1985 did not include a discussion of the hesitation in market growth implied by Moore's chasm theory. The behavior of prior runs of the interim AVID model is examined, showing that a "chasm-like" behavior is simulated to occur under some circumstances. We also noted that the "chasm-like" behavior requires the existence of separate group preferences, as posited by Moore.

In part to test whether there is evidence for the existence of an early group (including Moore's innovators and early adopters) currently particularly interested in hybrids (and who have preferences distinct from those of the majority), a survey was constructed and conducted. The positions of the diesel and hybrid light-duty passenger cars and trucks in the "technology adoption life cycle" are examined with this mid-2004 stated consumer preference study of 1,036 households. Implications of the technology life cycle for historical consumer preference estimates obtained for use in prior logit models of market share are briefly discussed. Survey respondents are segmented into subgroups, or markets, in light of hypothesized heterogeneous attributes of consumers within the product life cycle. Emphasis is placed on delineating the preferences of new, rather than used, light-duty-vehicle buyer segments. The hypothetical life-cycle segments addressed are "early adopters, early buyers, and majority buyers." These categories are compared with the five categories in the high-technology-adoption life-cycle paradigm used by Moore.

One purpose of the survey as a test of the reasonableness of the buyer groups used in AVID, and, if the categories are reasonable, is to estimate how large — in terms of share of the total new light-duty-vehicle market — each might be. The implications of the survey for use of the "rational buyer" model of consumer trade-offs of incremental new vehicle capital cost (of a diesel or hybrid) against reduced fuel cost are addressed. Competition among buyer desires for fuel efficiency, acceleration, and towing are also addressed, as are the effects of gender, age, income, number of children, location and education.

(Note: Aside from the detailed discussion of quantitative inferences about Moore's model and of the relationship of AVID structural assumptions to the innovation diffusion literature before 1985, a condensed version of the discussion in this appendix has been published as a paper titled "Hybrid and Diesel Vehicle Introduction Influences in the Technology Adoption Life Cycle" in the CD-ROM of peer-reviewed papers accepted for presentation at the 84th Annual Meeting of the Transportation Research Board in Jan. 2005.)

A.2 INTRODUCTION

The research discussed in this appendix followed completion of the body of this report and its review. A significant portion of this appendix was published as TRB and TRR documents. However, because of length restrictions, not all findings in the appendix were included in those documents. Further, scholars of consumer preference may be interested in the actual questions asked in the May 2004 ORC survey used for this appendix and the TRB and TRR papers. These questions are published here.

In the body of this report about the ongoing development of an AVID model, we hypothesized the existence of three key new light-duty-vehicle (LDV) buyer groups that require separate market penetration submodels within the larger AVID model of transition from one vehicle technology to another. The three groups were the early adopter, early buyer, and majority buyer. Among the three groups, early adopters were asserted to place far higher "hedonic" values on such vehicle attributes as fuel efficiency, acceleration, range, luggage space, maintenance, and top speed than the remainder of the buying population and to be much less concerned about vehicle price. Early buyers and majority buyers, in contrast, were asserted to be similar in their approach to buying, using deliberate "rational" net present value (NPV) methods to evaluate quantifiable annual costs (such as fuel cost and maintenance cost) so that they may determine an appropriate incremental cost for a more efficient vehicle technology.

Within these two groups, however, the early buyer and majority buyer were argued to vary in terms of inherent need to control fuel cost or maintenance cost. The early buyer was asserted to be a higher-income buyer who drives more miles per year than the majority buyer, and so early buyers more rapidly convert per-mile fuel cost and maintenance cost savings into NPV. The early buyer was also argued to be likely to place a higher value on such attributes as acceleration, luggage space, range, and top speed because they spent more time in the vehicle than the majority buyer and therefore benefited from these attributes. Similarly, since they also have higher income, early buyers value time more highly, so driver ability to accelerate quickly, drive fast, bypass refueling stations, and spend less time in maintenance facilities are argued to be more valuable to this group.

The foundation assumptions of the model are that the marketplace is heterogeneous and, although there is a significant "deviant" subgroup within this heterogeneous marketplace (early adopters who largely ignore vehicle price in determining which vehicle to choose and how much fuel and maintenance cost to accept), the vast majority of the marketplace can be properly characterized by the "rational buyer" model by using NPV logic. Sources of conflict of the modeling approach with those of some of the cited authors are the following:

1. Results from both stated-preference and revealed-preference surveys are informative about consumer behavior, and results of neither survey type can be neglected if a valid AVID model is to be assembled.

2. Present and past "models" of transitions simply do not properly address how difficult it is to successfully introduce a new vehicle technology to market.

3. Consumers (early buyers and majority buyers) do value significant changes in fuel cost according to NPV logic, and higher-income consumers use a lower discount rate than lower-income consumers.

The survey examined within this appendix is a stated-preference survey. A stated-preference survey is one in which consumers are asked what they would do (what vehicle type they would purchase in this case) in the future, conditional on information provided by those administering the survey. Revealed-preference surveys examine how buyers have actually behaved after the purchases have been made. One problem with advanced vehicle technology or products under development is that it is not possible to do revealed-preference surveys. The stated-preference survey is the only tool available, and it is in fact used to design and develop products in a way that will enhance the chances of their success.

Conflict 1 — Greene and Chin (2000) examined stated-preference surveys and revealed preference surveys from the literature; observed that the coefficients were extremely different; and recommended to their sponsor, the Energy Information Administration (EIA), that the EIA LDV alternative fuel and advanced vehicle market penetration model rely only on the results of revealed-preference studies. We argued that this is not a valid conclusion and incorporate the results of both stated-preference surveys and revealed-preference surveys. In AVID, our argument, in part, is that stated-preference studies are unduly biased by early adopters, who do not use vehicle price as a primary determinant of vehicle choice. We constructed a two-segment model in which one segment included evolving coefficients. The evolving coefficients segment started with stated-preference coefficients as a representation of early adopter behavior and adapted those coefficients over time to simulate an evolution of the market to dominance by early buyers. The resulting model did indicate that the so-called “early group,” including early adopters and early buyers, was the segment that has allowed early hybrids to be successfully introduced into the market.

The primary reason for the recommendation by Greene and Chin that the results of stated-preference surveys not be used is that the implied dollar value of vehicle attributes imputed from stated-preference models are too high to be compatible with NPV implications. One factor asserted here to play a role is the use of a lower discount rate by higher-income consumers. The argument that high-income consumers use a lower discount rate than low-income consumers was developed by Hausman (1979). Consistent with Hausman’s findings, we noted that the stated-preference study by Morpace International Market Research and Consulting (2003) implies that survey responses of most households that intend to buy new cars and have incomes exceeding $50,000 per year have a willingness to pay considerably more for a specified annual fuel cost savings than would those with incomes less than $50,000 per year.

Conflict 2 — Leiby and Rubin (2003) estimated that the hybrid vehicle share of the new LDV market could jump from zero to over 70% within two years if buyers were offered a $2,400/vehicle subsidy. McNutt and Rodgers (2003), in the same session at the same conference, included a chart with a less rapid change of share of alternatively fueled vehicles to illustrate that the Energy Policy Act of 1992 was flawed because it implied that an even slower rate of change (than simulated by Leiby and Rubin) of new vehicle technology was possible.

Conflict 3 — Kurani and Turrentine, surveying a number of potential vehicle buyers, found that only a very small fraction of that population was able to even approximately compute the net present value of fuel cost savings. They conclude therefore that the rational model of consumer behavior is implausible. Because this is the foundation of AVID (and of much decision making in government), it is desirable to determine whether the findings are valid and the rational buyer model should therefore be thrown out or its use greatly curtailed. Moore (p. 20), a proponent of using the "Technology Adoption Life Cycle," discusses the problem of marketing to the "early majority" (our early buyers) after succeeding with the early adopters. In discussing the challenge of getting a technology started within the majority market and making the difficult transition across the "chasm" from the early adopter market, he states that for the early majority, "good references are critical to their buying decisions. So what we have here is a catch 22. The only suitable reference for an early majority customer, it turns out, is another member of the early majority … no upstanding member of the early majority will buy without first having consulted with several suitable references." Elsewhere, he describes the majority of consumers as "*pragmatists* in orientation."

Our "solution" to the problem posed by Kurani and Turrentine is to explore the hypothesis that once the pragmatic majority buyer decides that a technology is interesting, that buyer seeks out other scarce, but important, expert pragmatists to acquire the information needed to make an intelligent (where use of NPV is defined as intelligent) decision on whether to make a purchase. Thus, the assertion is that the fact that buyers do not know how to use NPV analysis is not important — what is important is that they know where to find information from someone who does do NPV analysis.

A.3 DEFINING MARKETS ACCORDING TO MOORE'S TECHNOLOGY ADOPTION LIFE CYCLE

In her review of the AVID report, Amanda Miller, the principal investigator for the consumer preferences analyses in Graham et al. (2001), indicated, "the state-of-the-art that you'll find in the market research literature will differ considerably from the approaches that you've seen in the transportation-focused journals" that were cited in the draft AVID report. Subsequent investigation showed that Mahajan and Peterson had, in their 1985 book intended to address the problem, lamented the lack of cross-discipline fertilization by "diffusion modelers." Within their book, they discuss an approach we thought was original in AVID — drawing a distinction between "potential and actual adopters." Potential adopters are the subject of stated-preference studies and this report. Miller recommended a popular (in comparison to the academic approach in Mahajan and Peterson) 2002 book by Moore, "Crossing the Chasm." We rely heavily on the latter applied discussion by Moore in this appendix.

Moore (2002) defines a market in the following way:

- A set of actual of potential customers,
- For a given set of products or services,
- Who have a common set of needs and wants, and
- Who reference each other when making a buying decision

What we emphasize here is "set," "common needs and wants," and "referencing" when making a buying decision. The products in question are hybrid and diesel vehicles. The sets are early adopters, early buyers, and majority buyers. The emphasis on referencing helps explain why, even though Kurani and Turrentine (2004) have demonstrated that few consumers can do NPV calculations, the early buyer and majority buyer market can exhibit the behavior of the rational buyer.

A.3.1 Moore's Sets of Consumers

Moore's sets of consumers are innovators, early adopters, early majority, late majority, and laggards. Our mapping is roughly:

- Early adopters = Moore's innovators and early adopters,
- Early buyers = Moore's early majority, and
- Majority buyers = Moore's late majority.

Laggards are simply ignored, more or less as Moore recommends. With regard to understanding how to get a new product into the market and determining how successful it can be, laggards are essentially unimportant. Moore characterizes innovators as a very small group of the population. "Innovators pursue new technology products aggressively. …There are not very many … Their endorsement reassures the other players."

Early adopters are a larger group, but like innovators, they do not make decisions "pragmatically." "Because early adopters do not rely in well-established references in making buying decisions, preferring instead to rely on their own intuition and vision, they are key to opening up any high-tech market" (p. 12). However, Moore also states that for early adopters, "the endorsement of innovators becomes an important tool" (p. 14).

Thus, on the basis of Moore's arguments, the early adopter group that we seek to characterize would include his innovators, who influence his early adopters, and neither of these groups makes pragmatic decisions. We argue that it is largely the presence of these respondents in stated-preference surveys that distorts the statistical results, making the results seem implausible to those who wish to understand the majority of the market, the pragmatists. Note that the stated-preference surveys cited for this report each attempted to determine consumer reaction to a technology very different from the mainstream technology — a situation by its nature that should get innovators and visionary early adopters excited and interested.

Revealed-preference surveys, on the other hand, characterize the existing majority market. If conducted at a time when no radical innovations are being attempted, the mix of technologies from which consumers may choose will be relatively narrow, and the results should be dominated by the vast majority of consumers, who are pragmatists, choosing among similar technologies. We suggest that, in the absence of a new technology within such a market, early adopters will simply behave much like majority buyers.

Moore argues that visionary early adopters are incompatible with pragmatic majority buyers. Moore states, “early adopters do not make good references for the early majority” (early buyer in our terminology).

Moore’s late majority and our majority buyer category may be called “conservatives.” They “will not support high price margins. Nonetheless, through sheer volume, they offer great rewards to the companies that serve them appropriately.” In our case, the reason that majority buyers do not support high price margins is that they are not fascinated with the technology of the car (like innovators), nor do they need the car as much as early buyers. Thus, they can more easily choose to spend their money elsewhere than on outstanding features for their household vehicles.

A.3.2 Quantitative Implications of Moore’s Qualitative Model

Moore’s work is qualitative rather than quantitative. His signature diagram is illustrated in Figure A-1. While Figure A-1 includes a vertical and horizontal axis, Moore’s diagram does not.

Moore’s exposition is clearly intended to reach an audience that is not quantitative in orientation. However, the context of Moore’s discussion implies that he is familiar at least with the basic innovation diffusion literature that uses the symmetric logistic curve as a model of product diffusion. Such a curve is illustrated in Figure A-2, along with a plot of the rate of change of market share associated with the logistic curve (this relationship is also illustrated in the introduction of Mahajan and Peterson). In addition, the general relationships of the AVID market segments relative to those of Moore are illustrated. The question mark is included

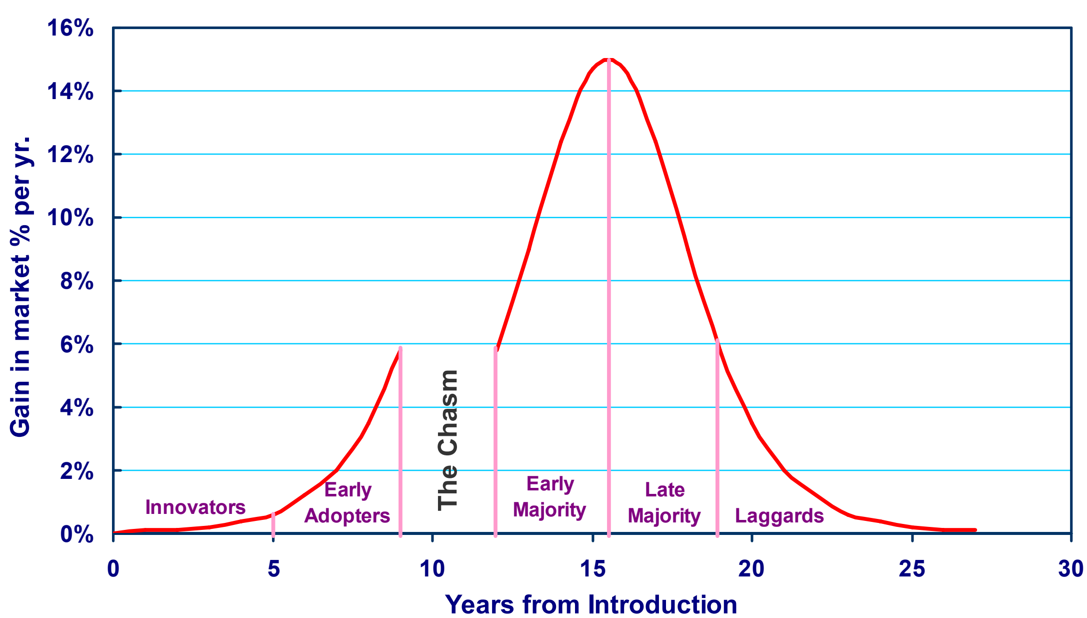

FIGURE A-1 Moore’s (2002) Signature Diagram, with Axes Added

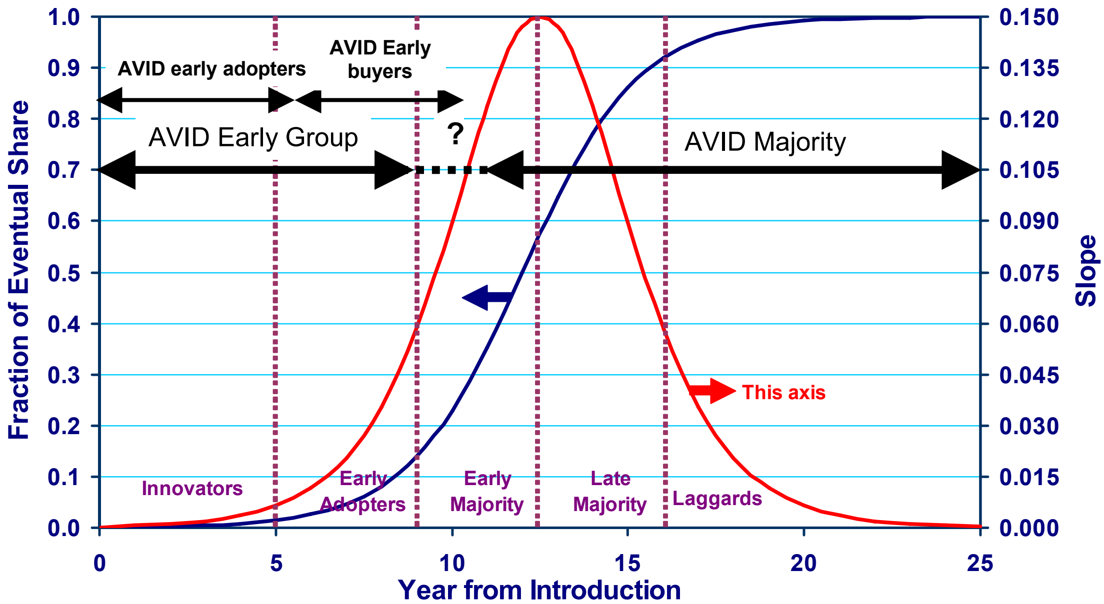

FIGURE A-2 Logistic Curve and the Normal Distribution of Time vs. Diffusion Rate

because the characterization of early adopters in this report actually has some aspects that are similar to Moore's characterization of the early majority. Thus, the overlap of the groups is imprecise at best.

Note that Figure A-1 is essentially identical to the diffusion rate curve of Figure A-2, except there is a period that Moore (1995) calls a "chasm" that separates the early adopters from the early majority. By plotting the axis as the diffusion rate (highly consistent with Moore's qualitative descriptions — see Moore [1995] for the description of "Tornado" conditions during the capture of the early majority), it can be seen that Moore implicitly assumes zero change in market share during the "chasm." In effect, this implies that Moore is talking about a hesitation in market growth, as illustrated in Figure A-3, rather than market failure. Were Moore discussing market failure or temporary contraction, the diffusion rate would have to turn negative during the "chasm" period.

Test simulations have demonstrated that the AVID model does, under some circumstances, include a hesitation in growth of the market as the transition from early adopters to early buyers begins (see Section 8, Figure 19). However, these runs also illustrate that a range of behaviors is possible, including no visible hesitation (see the case for 7% HEV incremental cost and $3.00/gal gasoline price — Figure 18) or actual contraction of share (see the case for 18% HEV incremental cost and $1.50/gal gasoline price — Figure 18).

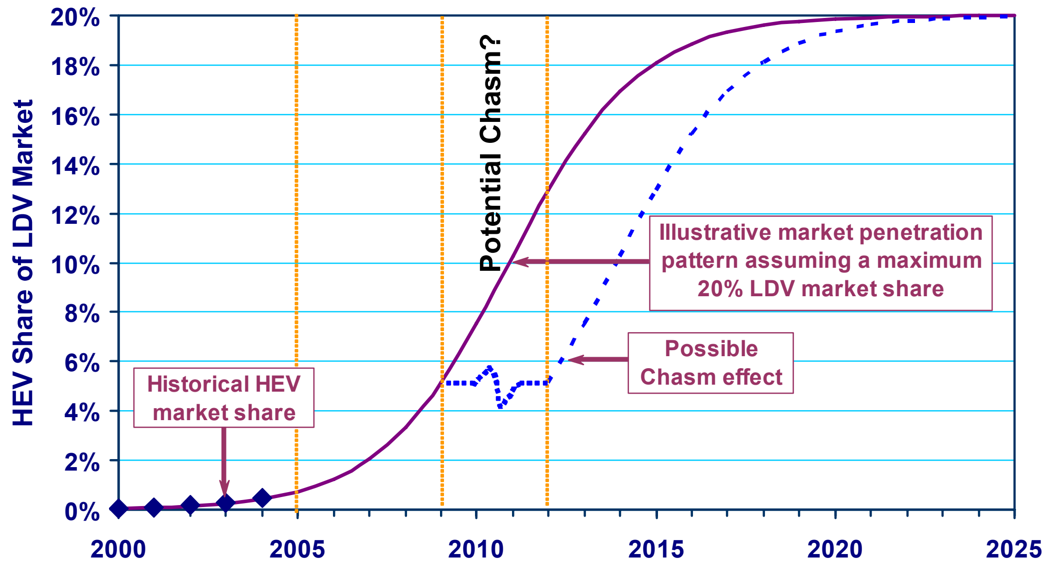

FIGURE A-3 Logistic Curve with "Hesitation" in Growth during Moore's Chasm

In the closing discussion of their 1985 book, Mahajan and Peterson argue that future diffusion modeling should address "rescinded, repeat, and replacement" adoptions. The 18% HEV cost increment, $1.50 case is a case that shows that AVID can simulate rescission under one circumstance. If a final model is constructed, it should be tested for an ability to simulate repeat adoptions of light-duty diesel vehicles as a function of oil (diesel fuel) price fluctuations, since the historical record shows that this has happened to the LDV diesel. The survey results discussed below imply that diesel and hybrid vehicles are not competing with one another at present, since they appear to appeal to very different types of customers. However, for longer-term projections with sustained high fuel prices and high market shares of diesels and hybrids, the possibility of one technology replacing the other should be examined. Similarly, the possibility that the two can complement each other under the most extreme oil price increases needs to be a part of a complete model, since hybrids equipped with a diesel engine instead of a gasoline engine are already in the market in commercial highway vehicles.

A.4 RELATIONSHIP OF AVID TO LITERATURE SURVEYED BY MAHAJAN AND PETERSON (1985)

At the outset, it should be pointed out that the innovation diffusion literature surveyed by Mahajan and Peterson shows essentially no concern for the evaluation of product attributes by use of NPV analysis of lifetime product costs or benefits. Economic content — such as the discussion of importance of price to product diffusion — is quite limited.

In their introductory chapter, Mahajan and Peterson (1985) divide simple models of innovation diffusion into "external influence, internal influence, and mixed influence categories." In the sample external influence model, share first rises steeply and then the rate of increase of share steadily drops. In terms of the rate of diffusion, the external influence model can be compared to the *second half* of the rate curve in Figure A-2. The pure external influence model "does not attribute any diffusion to interaction between prior adopters and potential adopters." In AVID, since the producer introduction decisions submodel is similar in pattern to the external influence model, it logically implies that each producer conducts its own evaluation of the desirability of hybrids (or diesels) and does not seek the advice of other producers. The external influence model is inherently compatible with the basic assumption of classical economics that the preferences (utility) of individuals are independent of one another and are formed by unchanging personal preferences relative to product attributes without influence by preferences of other buyers.

The internal influence model "is based on a contagion paradigm such that diffusion occurs *only through* interpersonal contacts." The prototypical diffusion curve for the internal influence model is the "S" curve identical to that shown in Figure A-2. The discussion of Moore's model above clearly implies that it is fundamentally an internal influence model, with the exception noted that there are major customer groups — the early adopters and early majority — that each use interpersonal contacts within the group, but none across the two groups.

Fundamentally, the AVID and NEMS models are philosophically external influence models. Although AVID assumes that there is a minority of the population that will pay more than a logical "rational" buyer should, the model adopted nevertheless implies that even these consumers are sensitive to prices and costs in the same fundamental manner as those consumers who fit the rational buyer model of reasonable NPV trade-offs. Although vehicle attributes are more highly valued by the early group, the difference is simply a matter of degree. Trading off attributes is still done in fundamentally the same way.

The notion that innovation diffusion modelers must estimate the "ceiling" for the product market is introduced by Mahajan and Peterson in their second chapter. In Figure A-3, this ceiling is arbitrarily set at 20%. To estimate the market penetration shown in Figure A-3, the share prediction of Figure A-2 is multiplied by the 20% market ceiling to arrive at the reference curve in Figure A-3. The model used in AVID to estimate the time-varying ceiling called "potential adopters" is essentially a weighted average of values of vehicle attributes — sometimes called a hedonic model. Mahajan and Peterson cite a proposal by Souder and Quaddus (1982) to use such an approach to estimate the ceiling market. Similar to the use of surveys for the AVID model, in the Souder and Quaddus diffusion model, individuals with expertise with the technology and potential purchasers were surveyed to construct the model "based on judgmental data of these individuals on eight attributes." The discussion of the Souder and Quaddus model is late in the Majahan and Peterson book, implying that this approach was regarded as relatively sophisticated among innovation diffusion modeling approaches.

The argument that "innovators are a dominant factor in the marketplace only during the short period required to achieve initial market penetration," which seems to echo Moore, is an argument that Mahajan and Peterson attribute to Robinson and Lakhani (1975).

In terms of Mahajan and Peterson terminology, the AVID model is a dynamic diffusion model. While the fundamental diffusion models assume that the market ceiling remains constant over the diffusion process (as illustrated in Figure A-3), "such an assumption is not tenable with regard to either theory or practice" (Mahajan and Peterson 1985). This point is made relatively early in the Mahajan and Peterson book, with much of the subsequent portions of the book discussing techniques to legitimately cause the market ceiling to vary, as it does in AVID.

The feature of the AVID model that includes potential (the market ceiling) and actual adopters is not new; according to Mahajan and Peterson, it has been implemented through 1985 in various fashions by Chow (1967), Dodson and Muller (1978), Lackman (1978), and Mahajan and Peterson (1978). Chow is quoted as arguing, "the number of computer adoptions was influenced by a technological change-price reduction effect." This price-reduction effect is clearly an important feature of the AVID model. A puzzling statement about the Chow model shows a lack of appreciation for the simple fundamentals of supply and demand. In describing the Chow model, Mahajan and Peterson describe this behavior: "users shift to products quickly when profitability is high." In AVID, *producers* shift to products quickly when consumer demand is strong — implicitly when profits are high. Consumer demand, on the other hand, will be less as the profit margin increases, because this implies that the producer is charging a higher price for the product.

Majahan and Peterson note that a "major criticism of basic diffusion models … is that they are of little use to agencies interested in diffusing an innovation because they consider innovation as a function of time only." Horsky and Simon (1983) "concluded that marketing activities such as price changes and product modifications are … likely to affect the eventual number of adopters." They stressed the importance of decreases in production costs as a result of learning early in the product life cycle, which is also recommended to be an important feature of AVID. Horsky and Simon believed that "firms will tailor their products to different market segments as the interests of those segments become apparent," thereby expanding the eventual number of adopters.

Clearly, the discussion in this report suggests that Toyota and Honda are doing what Horsky and Simon believed that firms would do. Those actions, in turn, support the notion that specific market segments (such as early adopters and majority adopters) need to be delineated by firms in order to maximize product success. Because it is included in Majahan and Peterson's section citing the needs of government agencies, the discussion of Horsky and Simon's logic essentially implies a recommendation that government agencies address the importance of market segments when examining potential markets for the development of products that they support.

Horsky and Simon also argued that "to be correctly specified a diffusion model should include advertising as a source of information to innovators" because "…an increase in advertising in the initial period of diffusion will facilitate the overall diffusion process by informing possible innovators … and turn them into word-of-mouth carriers." Hagerstrand (1967) similarly "viewed diffusion as the transformation of a population from one with a low proportion of adopters to one with a high proportion of adopters by means of information disseminated through mass media and interpersonal contact." AVID does not include advertising. However, the discussion of Toyota and Honda strategies does include information concerning specifics of unique advertising strategies for innovators and early adopters of hybrids. These strategies are clearly consistent with Horsky and Simon's opinion about the merit of tailoring advertising to "market segments."

Mahajan and Peterson (1985) state, "the assumption that an innovation does not change over time is tenuous." Clearly, a premise of AVID is that transportation technology innovations do change over time and that these changes are a very important determinant of market success or failure of the technology.

Finally, we note that Mahajan and Peterson also briefly address the issue of spatial diffusion, noting that its consideration has been limited primarily to the discipline of geography. They suggest that construction of independent diffusion models for multiple regions is one modeling strategy, but it may be "inefficient" and miss interactions across regions. In any case, AVID is not conceived of at present as a regional or spatial model. However, the findings of the survey discussed below suggest that important regional differences — especially between metro and non-metro areas — exist with regard to consumer interest in hybrids versus consumer interest in diesels.

A.5 THE DIESEL VS. THE HYBRID

A.5.1 Hybrids

Our position is that the hybrid is a "high-tech" technology just entering the LDV market, while the diesel is a mature technology attempting to expand its role in this market. Thus, for early adopters, the diesel is not of interest. Accordingly, because the argument is that the diesel must succeed in the early buyer market, those who choose the diesel should behave as if the "rational buyer" model is correct. The patterns of choice for the hybrid, however, should not be consistent with the rational buyer model. At this point, the "vision" of a future world with hybrids should be causing early adopters, regardless of need, to be expressing and exhibiting the nature of their interest through purchases of hybrids. Similarly, innovators (within our early adopter group) — who "appreciate the technology for its own sake" (Moore 2002, p. 30) — should now be purchasing hybrids.

David Hermance (2003) of Toyota recently asserted that early adopters represent only about 3% of the market. He indicated that Toyota is now interested in an "early majority" (our early buyer) rather than early adopter. Toyota has so far introduced three generations of hybrid passenger cars, named Prius. The Prius was designed as a separate vehicle with only a hybrid powertrain available. However, as Toyota moves forward, it will be making the hybrid powertrain the optional premium, high-power drivetrain on two "small" sport utility vehicles (SUVs). Each of the three generations of Prius — the first only available in Japan, with the second and third available in the United States — has had more rapid acceleration and higher fuel economy. Plotkin et al. (2001) published estimates that the cost/benefit relationship for hybrids improves as the performance level (in terms of 0–60 time) improves, although their study was far too pessimistic with respect to the level of fuel efficiency benefits Toyota has been able to produce in its Prius hybrid.

Popely and Mateja (2004) are among the popular writers noting that the “green” image is being replaced in 2005 and beyond as hybrids appear to be moving upscale in the powertrain market, providing considerable levels of horsepower. Synovate Motoresearch (2004) recently indicated that a survey of “1500 owners and intenders of new vehicles in the US shows that 54% are more interested in a hybrid than they were one year ago.” Synovate Motoresearch noted that in 2004, “manufacturers are finally offering hybrid vehicles that require no sacrifice of the characteristics that drive vehicle purchases.” They also noted that fuel prices have finally moved up enough to get fuel cost to become important to mainstream U.S. consumers. Toyota’s recent marketing strategy for its future hybrids has focused on being “green” and having performance as well (Toyota Motor Corporation 2003). According to the Synovate Motoresearch survey, and the results of this study, this advertising, in conjunction with prior hybrid vehicle production by Toyota and Honda (and high fuel prices), has dramatically increased consumer interest in hybrids.

The early buying pattern for the Prius was dominated by male purchasers, according to Heraud (2001) (63% men for the Prius, 44% for the Camry, and 45% for the Corolla). Hermance (2003), two years later, indicated that the purchasing demographics for the Prius changed over time, from early 72% male purchasers to a 48% share in 2003, which is now very similar to the purchasing pattern for the Camry and Corolla.

In Moore’s terms, and according to Hermance’s statement, Toyota hybrid powertrains have reached the point in the technology adoption life cycle where they must “cross the chasm” between early adopters and early (majority) buyers. In these terms, our survey comes at an opportune time in the young history of the hybrid passenger car and light truck.

Honda also introduced hybrids and has been selling them for a few years. Its first hybrid, like Toyota’s, was a purpose-built hybrid — the two-seat Insight. This was a very high-tech vehicle — it incorporated a lot of aluminum, in addition to a new hybrid powertrain. It remains in the market in very small numbers. Clearly, this vehicle was sold below cost and acted as a test bed. This example followed Moore’s advice about innovators. He said that they are very forgiving of mistakes if treated with respect, because they want to be a part of the process of introducing new technologies. However, according to Moore, they will not pay a high price. Thus, to develop long-term markets for a new technology, Moore advises first selling the technology, at a cost below the cost of production, to innovators. The Insight, which is clearly a unique high-tech vehicle targeted to a small, unique market (Moore’s innovators), was the first hybrid in the United States.

J.D. Power (Malesh 2000) found that an unusually large proportion of Insight buyers actually bought the vehicle as an additional household vehicle rather than as a replacement vehicle. While the fraction of all buyers who add a vehicle, according to Power (as reported by Malesh), was 19% in 2000, the fraction that added the Insight was 43%. Even if the percentage of Insight buyers adding a vehicle was compared with the percentage of buyers adding “sports cars” it still exceeded the 29% of buyers who were adding vehicles for the sports car category. In fact, the Insight was relatively unique even among other two-seaters, most of which could legitimately be called sports cars. It had far lower acceleration capability than any of these vehicles, and it did not offer a convertible option, which many of the two-seaters include.

Honda advertised the Insight as a virtuous "green" vehicle. Malesh concluded that low emissions and outstanding fuel efficiency were clearly the focus of consumer interest. Malesh noted that 86% of Insight buyers said fuel economy "was extremely important" versus 44% among all new vehicle buyers. This was consistent with Hermance's 2003 characterization of the earliest Prius buyers, more than 80% of whom highly valued fuel economy — far more than for any class of conventional vehicle. Unfortunately, neither Malesh nor Hermance reported the miles driven by Insight and Prius buyers relative to all new vehicle buyers. Malesh did note that the second most important attribute of the Insight cited by its buyers was the "nebulous response: they just liked the vehicle."

Retrospective consideration of the hybrid powertrain introduction strategies of Honda and Toyota suggests that both companies judged the early adopter to be an individual who would prefer a unique vehicle. They may have designed vehicles with this buyer in mind, in order to get the hybrid powertrain into the market and refine it before targeting it at majority buyers. Honda followed with the Civic hybrid, for which the hybrid powertrain was just an option in the Civic model, in addition to multiple conventional powertrains. At present, the near-term future of the hybrid powertrain appears to be as an option within existing vehicles. Ford's new hybrid is the Escape SUV, in which the hybrid powertrain is offered in addition to conventional powertrains with four- and six-cylinder engines. General Motors has introduced a hybrid powertrain option in limited numbers in a few states in its Sierra pickup truck (Truett 2004). Both GM and Ford are several years behind Toyota and Honda and will be selling thousands of vehicles in 2005, while Toyota and Honda sold over 80,000 Prius and Civic models in the United States in 2004, with three new U.S. models to be added in 2005.

A.5.2 Diesels

Although the diesel engine in a passenger car is not particularly common, the diesel engine in trucks is highly successful. LDVs are regulated differently above and below 8,500 lb of Gross Vehicle Weight (GVW), where GVW refers to maximum weight of the vehicle combined with the heaviest load that it is designed to haul. As consumers have moved to bigger and bigger trucks, there are several trucks, with diesel engines readily available, that are now marketed primarily or secondarily as passenger vehicles in the category of 10,000 lb GVW and less. Monohan and Friedman (2004) have computed the historical share of diesel engines in vehicles less than 10,000 lb GVW and have estimated that the market share of diesels in this category is significant and has been rising over the last decade. In the late 1970s and early 1980s, diesel engines were introduced in passenger cars, with a 5.9% peak in share being realized in 1980, the year before gasoline prices peaked. These diesel engines proved to be unreliable and, in some cases, could not maintain low emissions over their lifetime. When gasoline prices also fell, the LDV diesel market share collapsed. Not only did the diesel not "cross the chasm" from early adopters to majority buyers, it actually experienced negative diffusion and disappeared for a time from the LDV market representing vehicles less than 8,500-GVW. However, diesel technology has improved dramatically and steadily increased share in the 8,500–10,000-GVW category in the 1990s, and the share moved steadily upward when gasoline prices rose again.

Davis and Truett (2002) have examined the trends in the 8,500–10,000-GVW category. The pattern shows a rising share of diesels in conjunction with and shortly following the gasoline price shock of 1988–1990, a fairly steady share from 1993 to 1997, a collapse in share in conjunction with the gasoline and oil price collapse of 1997–1998, and an immediate revival in 1999 as gasoline prices rose again. The vast majority of diesel engines were installed in pickup trucks (18–47% over the 1989–1999 period examined), with a much smaller share in vans and SUVs (8–15%).

Davis and Truett were not able to reliably estimate the number of vehicles of this category sold by year. However, according to their estimates, sales of the diesel in this vehicle class probably were within the range of 120,000–240,000 in most years studied. More recently, the Center for Automotive Research, under contract to Argonne, has compiled sales data for diesel truck engines in trucks up to 10,000 lb GVW and has estimated an increase from 181,000 units in 1999 to 301,000 in 2003. Light-duty diesel sales in cars totaled 17,000 in 1999, rising to 30,000 in 2002, and dropping to 26,000 in 2003 (Smith 2005). The share of diesel engines, on the basis of these data, has risen from 1.2% to 2.0% of the total market in the 10,000-lb-GVW category and lower. This market share is considerably lower than that in 1980, but it represents a rapid increase. Thus, the present market for the LDV diesel engine is considerably larger than that for the hybrid.

A.5.3 Summary

In summary, for 2004–2005, the hybrid has been sold in a small two-seater (Insight) and in the compact (Civic) and mid-size (Prius) EPA size-class segments. For the 2005 model year, three hybrids are scheduled for the small and mid-size SUV segments: the Ford Escape, Toyota Highlander, and Lexus RX model. One more is scheduled for the mid-size passenger car class (Honda Accord). The GM Sierra hybrid pickup truck is available in very limited quantities, while the DaimlerChrysler hybrid diesel may never be made available to the public (Truett 2004). In contrast, 92% of diesel engines in 2003 were sold in vehicles representing 8,500–10,000-lb-GVW segment. Well over 95% of the hybrids sold to-date are sold in the class of vehicles less than 8,500 lb GVW.

Davis and Truett listed diesel engines in 12 models within the 8,500–10,000-lb GVW class, with diesel engine options offered by GM, Ford, and DaimlerChrysler. Only the Ford Excursion SUV was available with a diesel engine. Toyota and Honda did not have any diesel vehicles in the 8,500–10,000-lb GVW class.

A.6 SELECTED/HIGHLIGHTED SURVEY RESULTS

One purpose of the summary of survey results (ORC 2004) in this appendix is to try to develop a better understanding of the attributes of subgroups that constitute potential markets for 2005 and beyond hybrids, which are considerably different from early hybrids through 2004, and to examine the subgroups most receptive to refined diesels.

This discussion reports on results of a survey conducted by the Opinion Research Corporation (ORC) International, CARAVAN Services, in May of 2004. The survey obtained and reported on 1,036 respondents. The majority of the discussion of results is based on the summary provided by ORC. Results at the end of this section were based on our analysis of the survey data, which were provided by the U.S. Department of Energy.

A.6.1 Gender

Only 13% of female respondents indicated an interest in purchasing a pickup truck, compared to 23% of males, which is a significant difference. Females would pay a mean value of $322 for an optional fuel tank that would allow drivers to go 50% longer between fill-ups, while males would only pay $185, which is significantly less. For females, 31% responded that the availability of diesel fuel "is a serious enough problem that they would or might not consider buying diesel," while only 23% of males responded similarly. The difference was statistically significant. Most respondents were able to refuel conveniently when on a trip that they had to make anyway, but males were able to do so 90%, significantly more often than females, at 86%. On average, males were willing to pay slightly more for a vehicle that could save $400 annually in fuel cost (at $943, compared to $877 for females).

Males reported that if they purchased a new vehicle they would drive it an average of 17,900 miles per year in the first three years of ownership, while females reported they would drive 15,800 miles, which is statistically significantly less. Of males, 57% reported they would drive more than 15,000 miles per year, compared to 43% of females, which is a significant difference. Males indicated that if given $1,000 to spend on quicker acceleration, fuel economy, or towing capability, they would allocate $272 to acceleration, while females indicated they would only allocate $225, which is a statistically significant difference. Conversely, females would allocate $644 to fuel economy, while males would allocate $572, which is also a significant difference. On average, men expected to sell a vehicle they had purchased new after 100,000 miles, females after 90,000, which is a statistically significant difference. When asked to name a specific hybrid vehicle model, females reported, "don't know" 66% of the time, while 37% of males reported "don't know."

Toyota and Honda were equally well known for their hybrid vehicles. Of males, 35% reported that they knew of a Toyota hybrid — the same percentage reported that they knew of a Honda hybrid. The corresponding percentages for females were 17% and 14%, respectively, which are statistically significantly lower than those for males. Although 66% of females could not name a hybrid, 41% responded that they would "Definitely, or were Very likely to, or were Likely (DVL) to" buy a hybrid, which was very close to the 45% reported by males. Consistent with concerns expressed about ability to refuel and willingness to pay for added range in order to go longer between fill-ups, females responded only 18% of the time the DVL response for a diesel, while 27% of males responded affirmatively to that question set. This difference was significant.

Comment: The responses imply that females value range and infrequent refueling of a vehicle more than males, which is consistent with a greater preference for hybrids than for diesels.

A.6.2 Age

Responses from selected age groups are provided in Table A-1. Generally, inclusion of responses is based on findings of significant differences among the age groups.

Column two of Table A-1 indicates that the percentage of respondents intending to purchase or lease a new vehicle generally rises with age, through the working years. At retirement age, there is a sharp drop. Willingness to pay for added range drops steadily with age, until retirement age, when it increases. Young persons indicate a willingness to pay considerably more. We note that the higher willingness to pay for fuel economy should be directionally consistent with the findings of the Morpace International study, because those in the age categories 18–34 are much more likely to represent one-vehicle households, for which the Morpace results implied greater willingness to pay for reduced fuel cost (see discussion in the section on income, below). However, the pattern of responses to the question of how much annual savings would be required to compensate for an additional $1,200 in cost are inconsistent with the prior question.

The two questions on willingness to pay for fuel savings, or requirement for fuel savings if the vehicle is more expensive, imply that a very short payback period is required by most respondents (less than three years). Note that 49% of respondents to the survey expect to drive a vehicle purchased new 15,000 or more miles per year, *and 25% anticipate driving 25,000 miles or more a year.* For average expectations of selling a vehicle in 90,000 miles, this means that the vehicles would be held for about 4–6 years, so average new car purchasers expect to get their money back in about half of the time they expect to hold the vehicle. The answers are inconsistent. Young persons (18–34) indicate they are willing to pay far more for an annual

TABLE A-1 Responses to Selected Questions as a Function of Age

Age Group and Row Letter	Percent Purchase or Lease New LDV	Dollars for Fuel Tank to Go 50% Longer	Extra $ for $400/yr of Fuel Cost Savings	Fuel $ Cut Needed/yr if Engine is $1,200 More	Share of $1,000 Allocated to Acceleration	Share of $1,000 Allocated to Fuel Economy	Percent Naming a Hybrid
18–24 (D)	30	721 (EFGHI)	1209 (FHI)	755 (I)	312 (GHI)	535	62
25–34 (E)	37	249 (H)	1,264 (FGHI)	688 (I)	264	594	54
35–44 (F)	46 (DI)	215	838 (I)	681 (I)	249	587	48 (D)
45–54 (G)	41	160	904 (I)	561 (I)	237	643 (D)	47 (D)
55–64 (H)	51 (DE)	109	733	642 ((I)	217	615	41 (DE)
65+ (I)	35	178	491	372	211	669 (DF)	35 (DEFG)

Note: If a row letter (each row is assigned a letter from D to I) is provided in parentheses, it means that the value in that row is significantly different from the value in the row with the letter label.

savings of $400 per year, but then they imply that they would require somewhat higher annual savings than older persons in order to offset a $1,200 cost increment for fuel efficiency. This inconsistency is consistent with Kurani and Turrentine's finding that consumers are not very good at estimating payback periods. These responses are not consistent, according to the rational buyer model, with the level of interest expressed in hybrids (discussed later), the incremental cost of which would take several years to pay back.

The respondent's allocation of a hypothetical $1,000 to spend on greater acceleration, fuel economy, or towing implied that as age increases, consumers will spend relatively more on fuel economy. The expressed higher preference of young persons for acceleration is not surprising and is consistent with Kavalec's (1999) findings. Young persons had a much greater awareness of hybrids than older persons. Perhaps the shift of emphasis in coming hybrid powertrain configurations toward performance helps explain the large jump in interest in hybrids. Although significantly greater than only the responses of the 55–64 age group, the 18–24-year-old age group did indicate the greatest agreement of any age group with the statement that they want to be among the first to own a new technology. Thus, the combination of an emphasis on performance and innovative technology appears to have caused a significant increase in interest on the part of young buyers. In terms of the responses to the question about "likelihood of buying," the 18–24-year-old group showed the greatest interest in both hybrid and diesel vehicles. At the other end of the scale, those aged 65 and above showed the least interest in both technologies. Thus, while this interest by young persons indicates promise for the future, it is also true that, for the most part, the youngest members of the population have the least ability to purchase expensive hybrid or diesel technology. More encouraging was the fact that the highest response (20%) to the "definitely will buy" a hybrid question response option was for the 25–34-year-old group, which will move into prime earning age in the next two decades. For this same age group, the "definitely will buy a diesel" response was least among all age groups (4%), aside from those 65 and over (1%).

A.6.3 Region

Aside from the Prius, which was named by 21% of those asked to name a hybrid in the western United States, there were no significant regional differences in awareness of hybrids. The response about the Prius in the West was greater than the 15% response in the Northeast and significantly greater than the 13% response in the North Central and South regions. In the South, 38% of respondents indicated that availability of diesel fuel is not a problem — they said it is available everywhere. This percentage was significantly more than that for the Northeast, at 29%. The value for the North Central region was 36%, close to the South, while for the West it was 33%.

A.6.4 Metro vs. Non-Metro

The incremental fuel economy benefits of hybrids are greatest in urban driving and are considerably better than the diesel in very congested driving. The diesel, however, provides greater gains in fuel economy under freeway and rural driving conditions. Either Toyota and

Honda have focused advertising in urban areas, or consumers interested in hybrids have learned that hybrids are of more value in reducing fuel consumption in urban (metro) driving than in rural (non-metro) driving. Metro residents significantly more frequently named Toyota (28% vs. 18%), the Prius (17% vs. 9%), Honda (26% vs. 18%), and the Civic (5% vs. 1%) than did non-metro residents. The awareness of the Ford Escape was far less, and the differences were not significant, but 3% of metro residents mentioned the Escape, while only 1% of the non-metro residents named the Escape. Consistent with the high awareness of the hybrid in metro areas, 17% of metro respondents indicated that they would definitely buy a hybrid or were very likely to buy one, while only 11% of non-metro residents provided this response.

In contrast, when a GM hybrid was mentioned, non-metro respondents were more often aware of it, at 5% total for GM (vs. 2%), which is a significant difference. Although it is true that the GM hybrid is a pickup truck, only one respondent to the survey correctly mentioned the model (Sierra). Nevertheless, we note that consumer awareness of the GM hybrid should be greater in non-metro areas, since it is a pickup, and respondents who planned to purchase or lease a new vehicle mentioned a pickup significantly more frequently in non-metro areas (26%) than in metro areas (16%). Non-metro respondents indicated in 44% of responses that availability of diesel fuel was "not a problem, diesel fuel is everywhere," while metro residents provided this response only 32% of the time. Consistent with the more frequent indication that diesel fuel availability is not a problem in non-metro areas, non-metro residents more often indicated that they would definitely or very likely buy a diesel than did metro residents. Although the non-metro value, at 10%, was not significantly greater than the metro value, at 8%, the contrast with the results for the hybrid vehicles (11% and 17%, respectively) is dramatic and likely significant.

A.6.5 Income

Selected income responses are provided in Table A-2. Generally, but not always, inclusion is based on findings of significant differences among the income groups.

In the Morpace International Market Research and Consulting (2003) study, imputed willingness to pay for $1 of annual savings in fuel cost was 2.0 times the annual savings for two-vehicle households with less than $50,000 of income (i.e., an imputed $800) and 2.5 times for households with three or more vehicles (an imputed $1,000). However, for two-vehicle households with more than $50,000 of income, the amount was 5.2 times as much, and for one-vehicle households with less than $50,000 of income, it was 6.2 times as much. The response to one question in this ORC survey did indicate a lower discount rate for higher-income individuals — that is, a willingness to increase payments for $400 of annual fuel savings as a function of income.

Clearly, as income rises, the probability of purchase of a new vehicle rises. This finding has the most powerful statistical significance across respondent groups of any question. The probable frequency of purchase of new vehicles also rises with income. The proportion indicating that a new vehicle will be purchased or leased within the next three years rises with income. Lower middle-income households appear significantly more likely to purchase a pickup

TABLE A-2 Responses to Selected Questions as a Function of Income

Household Income ($) and Row Letter	Percent to Purchase or Lease New LDV	Percent to Purchase or Lease in Next Three Years	Percent to Purchase a Pickup Truck or Large Van	Refuel Frequently on Trip Made Anyway	Specify Over $1,000 for $400/yr Fuel Savings	Mean Miles per Year for New Vehicle for 3 yr	Strongly Agree "I want to Be First New Tech Owner"
<25K (B)	15	53	18	83	37	16K	17 (EF)
25–35K (C)	29 (B)	56	10	86	28	16.5K	16 (E)
35–50K (D)	40 (B)	59	32 (CF)	89	39	16.3K	16 (E)
50–75K (E)	52 (BCD)	64	20	93 (B)	48 (C)	18.0K (B)	5
>75K (F)	64 (BCDE)	75 (CD)	12	93 (BC)	44 (C)	18.1K (BD)	10

Household Income ($) and Row Letter	Share of $1,000 to Fuel Economy	Share of $1,000 to Acceleration	Share of $1,000 to Towing	Percent Naming Toyota Hybrid	Percent Naming Honda Hybrid	Know of a Hybrid	"Definitely Very" or "Likely" to Buy Hybrid
<25K (B)	608	254	138	15	17	32 (CDEF)	39
25–35K (C)	658	206	136	28 (B)	26	50	41
35–50K (D)	616	205	179	22	29 (B)	51	39
50–75K (E)	579	257	164	29 (B)	24	52	51 (BD)
>75K (F)	616	253	131	39 (BCDE)	27 (B)	60	49 (B)

Note: If a row letter is provided in parentheses, it means that the value in that row is significantly different from the value in the row with the letter label.

truck. Most respondents (83–93%) found it possible to refuel on a trip that they would make anyway. The proportion rose with income, with higher-income respondents finding it significantly easier than lower-income respondents. Higher-income respondents more frequently indicated a willingness to pay more than $1,000 in return for $400 per year of fuel cost savings. Higher-income respondents intended to drive their new vehicle significantly more miles per year for the first three years of ownership than did lower-income respondents. The latter two responses are compatible with increasing likelihood of purchase of vehicles for which added first cost results in reduced cost per mile, as income rises. These stated behaviors for LDVs are consistent with Hausman's observed behaviors for air conditioners and are favorable for hybrids or diesels.

Unfavorable for hybrids is the fact that as income increases, the proportion of respondents indicating that they want to be the first to own a new technology drops. Thus, for hybrids, this response implies that the perception of the hybrid powertrain — whether it is a proven technology or a new technology — will be critical if the target market is highest-income consumers.

Although there were no significant differences among income groups with respect to willingness to allocate shares of a hypothetical $1,000 to fuel economy, acceleration, or towing, we nevertheless examine the results. For incomes greater than $50,000, the weak evidence is that there is a slight increase in desire for acceleration and slight decrease in desire for fuel economy, relative to those with less than $50,000 of income. Although the towing amounts are not significantly different from one another, it is nevertheless interesting that the income category in which respondents allocated the highest amount to towing is also the income group that indicated a significantly greater preference for pickup trucks. Nevertheless, this finding does not indicate a higher likelihood that this income group would purchase a diesel (not shown).

Toyota appears to have been particularly successful in targeting the highest income group, since this group was able to significantly more frequently name a Toyota hybrid. Further, within the Toyota and Honda nameplates, respondents more frequently mentioned the Prius in particular than the generic term “Toyota hybrid” than was true for the Honda hybrids, the Civic and Insight. Knowledge of hybrids increases with income. The DVL response for likelihood of buying a hybrid increased notably for incomes above $50,000, indicating that advertising and awareness is prompting significant interest among higher-income new car buyers.

A.6.6 Household Size

The presence of three or more members in a household significantly increased the plans for purchasing either an SUV or minivan and significantly decreased the plans for purchasing either a small or large car. Family size did not affect probability of purchase of a pickup truck. Having three or more members in a household, or having children in the household, significantly increased the plans for driving a new vehicle more than 15,000 miles per year in the first three years of ownership. These patterns may bode well for the three 2005 small and mid-size SUV hybrids — the Ford Escape, the Toyota Highlander, and the Lexus RX400.

A.6.7 Education

Selected responses on the basis of education level are provided in Table A-3. Generally, inclusion of a response is based on findings of significant differences among the income groups.

The percent indicating intent to purchase or lease a new vehicle rises sharply with education, probably largely through effects of increased income. College-educated respondents are most likely to purchase or lease a new vehicle on a 4–6–year schedule, which is significantly more frequent than the schedule for high school graduates. In contrast, those with a high school education or less are far more likely than those who went to college to hold their new vehicle for a period longer than six years. High school graduates are significantly more likely than college graduates to hold a new vehicle for more than six years. Those with less than a high school education indicated a significantly greater concern over the availability of diesel fuel than any other education category.

High school graduates allocated significantly more of a hypothetical $1,000 to acceleration than did those who had attended college. Although the low numbers of respondents may have kept the result for those without a high school education from being significant, this group allocated almost the same average amount to acceleration as did the high school graduates.

TABLE A-3 Responses to Selected Questions as a Function of Education

Household Income ($) and Row Letter	Percent Purchase or Lease New LDV	Percent Purchase or Lease in 4-6 yr	Percent Purchase or Lease in >6 yr	Percent Purchase Pickup or Large Van	Diesel Fuel Access a Serious Problem	Know of a Hybrid	DVL to Buy a Diesel	DVL to Buy a Hybrid
High school Incomplete (O)	17	26	23	44	44 (PQR)	33 (R)	21	29
High school (P)	34 (O)	12	17 (R)	30 (QR)	28	41(R)	30 (QR)	36
College Incomplete (Q)	38 (O)	21	10	13	24	43(R)	20	40
College Graduate (R)	52 (OPQ)	31 (P)	4	11	26	62	18	53 (OPQ)

Household Income ($) and Row Letter	Share of $1,000 to Fuel Economy	Share of $1,000 to Acceleration	Share of $1,000 to Towing	Percent Naming Toyota Hybrid (Prius)	Percent Naming Honda Hybrid (Civic or Insight)	Percent Naming Ford Hybrid (Escape)	Percent Naming GM Hybrid (Sierra)
High school Incomplete (O)	518	295	187 (R)	9 [2]	16 [2]	5 [0]	3 [0]
High school (P)	556	289 (QR)	155 (R)	17 [7]	21 [4]	4 [0]	3 [0]
College Incomplete (Q)	607	229	164 (R)	22 (O) [14 (O)]	22 [4]	4 [2]	2 [0]
College Graduate (R)	670 (OPQ)	221	109	39 (OPQ) [25 (OPQ]	30 (OPQ) [11 (PQ)]	10 (PQ) 5 [PQ]	2 [0]

Note: If a row letter is provided in parentheses, it means that the value in that row is significantly different from the value in the row with the letter label.

College graduates allocated significantly fewer dollars to towing than any other education category and allocated significantly more dollars to fuel economy. This is a very favorable result for hybrids, which sacrifice towing capability to obtain increases in fuel economy.

A higher proportion of college-educated respondents knew about hybrids than any other education category. They were consistently able to more frequently name the specific hybrid models of Toyota, Honda, and Ford than any other education group. Their awareness of particular makes and models of hybrids was usually significantly greater than that of other education groups. Consistent with this demonstration of knowledge about hybrids, college graduates were far more likely than other education groups to provide a DVL response about the likelihood of purchasing a hybrid, with over one-half of college graduates providing an affirmative DVL response.

For the diesel, those with a high school education were significantly more likely to respond affirmatively to the DVL set of questions on the likelihood of purchasing a diesel, with 30% providing an affirmative DVL response.

A.7 AMOUNT OF DRIVING IN FIRST THREE YEARS OF OWNERSHIP, EDUCATION, INCOME, AND GENDER AS INFLUENCES ON INTENT TO PURCHASE A DIESEL OR A HYBRID

After individually examining the effects of driving, income, gender, and education on the likelihood of purchasing a diesel or a hybrid, we attempted to examine how these variables interact. Our major hypothesis for diesel buyers is that they are among the early majority, are pragmatists, and use NPV in evaluating whether or not to purchase a diesel powertrain. For hybrid buyers, our major hypothesis is that those buyers presently interested in them are early adopters, and so they will not make pragmatic decisions with respect to probable fuel savings. In other words, the probability that a buyer will select a diesel powertrain should rise as the buyer's annual mileage driven increases, but the probability that a buyer will select a hybrid will not rise on the basis of increasing annual mileage or will rise at a far lower rate than that for a buyer of a diesel.

We divided the responses into three reported anticipated annual-driving-distance categories: less than 10,000 miles per year, 10,000 to 20,000 miles per year, and greater than 20,000 miles per year. Eighteen percent of survey respondents reported they would drive their new vehicle 10,000 miles or less for the first three years of ownership, while 39% reported that they would drive their vehicles from 10,000 to 20,000 miles per year, and 34% reported that they would drive over 20,000 miles per year. Nine percent indicated they did not know. For our calculations, we ignored those who responded "don't know." Figures A-4–A-7 show the percentage of respondents within a specified income/gender/education category who anticipated driving within the specified distance category and who reported a DVL response for the diesel or hybrid.

For Figures A-6 and A-7, we lightly dotted the results for females, and we removed cases where there were only five observations. Figure A-6 shows that female respondents indicating a DVL response for diesels were limited in number. In contrast, Figure A-7 shows that DVL responses for hybrids were more frequent than those for diesels. Recall that females responded 66% of the time when asked to name a make or model of hybrid.

In the aggregate, a college education enhances the proportion of females interested in hybrids, regardless of income (based on totals — not presented in Figure A.7). For college-educated women, the total percent DVL for hybrids is greater than that for college-educated males, whether income is above or below $50,000. For respondents with a high school education or less, the total percent of DVL responses for hybrids by females was less than that for males.

The effect of some college or a college degree on the interest in buying a hybrid was positive; for a diesel, it was negative. *Among those intending to purchase or lease a new vehicle*, income was *not* an important factor in the level of interest in a diesel or hybrid, after yearly mileage and education were taken into account. However, recall that income was clearly a very strong factor in the probability of entering the group intending to purchase or lease a new vehicle (Table A-2, column 2). Toyota and Honda advertising clearly has succeeded in obtaining brand recognition for their hybrid vehicles among the highest-income groups and the most educated.

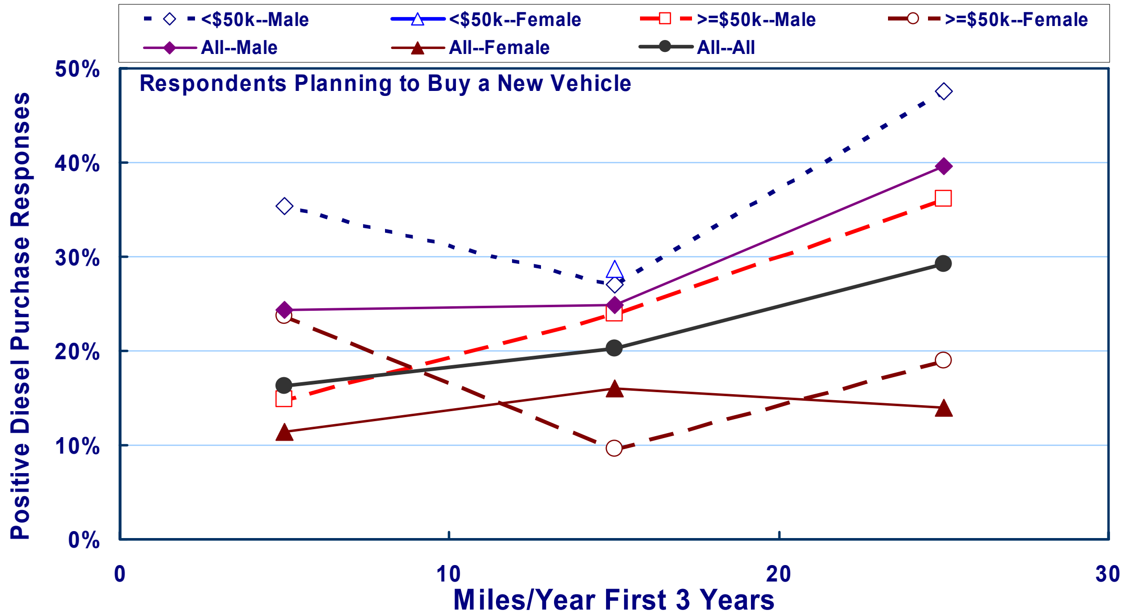

FIGURE A-4 DVL Likelihood of Diesel Purchase vs. Distance Driven, by Gender

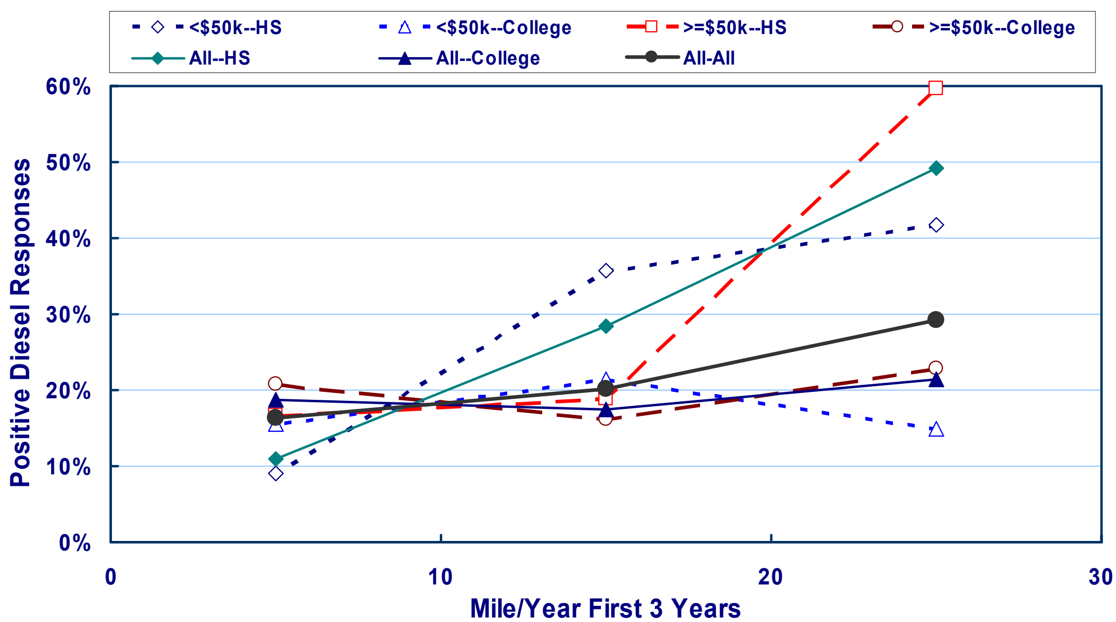

FIGURE A-5 DVL Likelihood of Diesel Purchase vs. Distance Driven, by Education

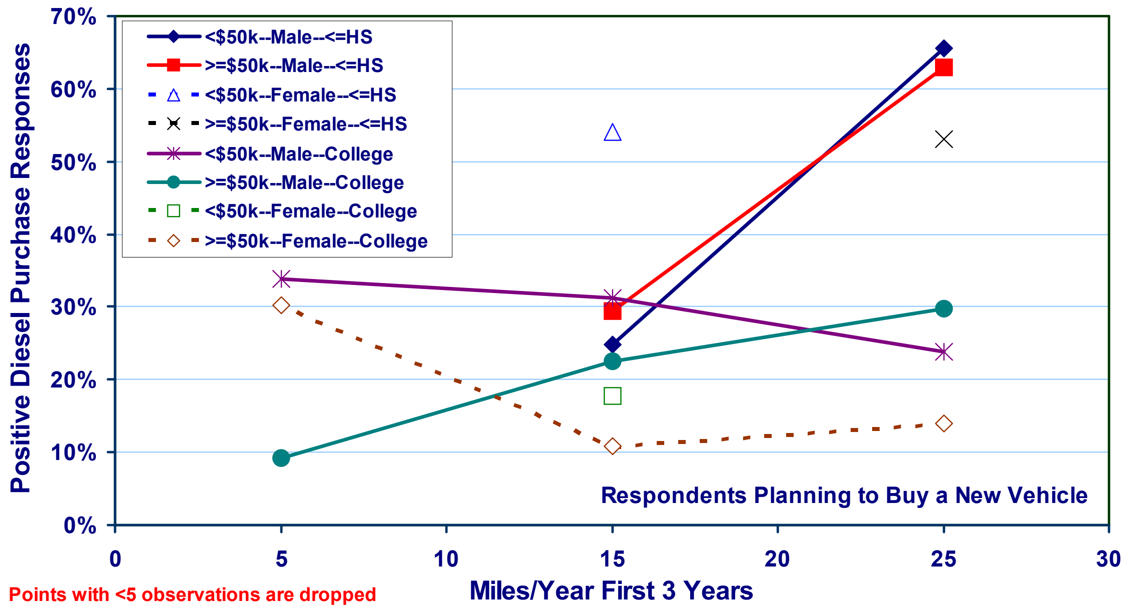

FIGURE A-6 DVL Likelihood of Diesel Purchase vs. Distance Driven, by Gender and Education

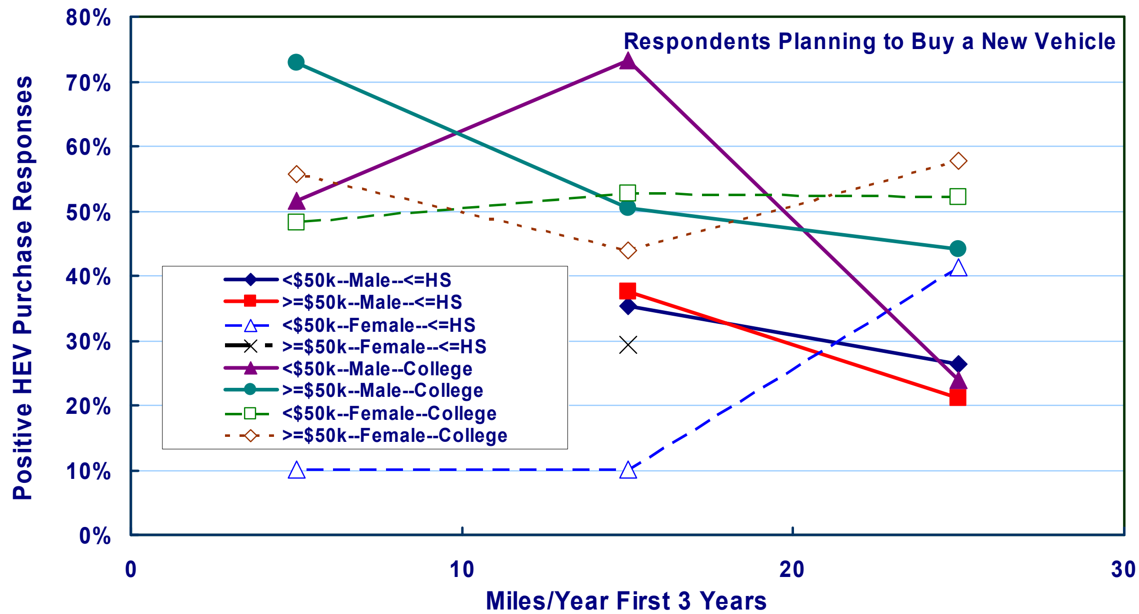

FIGURE A-7 DVL Likelihood of Hybrid Purchase vs. Distance Driven, by Gender and Education

The DVL responses for hybrids appear to be consistent with Toyota and Honda, creating a vision of a positive future for hybrids among the well educated. After income has caused a high probability of new vehicle purchase or lease, education appears to be the key incremental factor in "selling" the hybrid vision. Because annual mileage does not appear to have an influence on customers interested in hybrids at present (Figure A-7), it is logical to argue that the hybrid has not yet crossed the chasm between early adopter and early (majority) buyer.

For the AVID model, the percentage of early adopters specified in the first draft of the model was 15% of the population purchasing a new vehicle. The total responses in the subsequent ORC (2004) survey discussed in this report showed that 15% of respondents indicated that they definitely or very likely would buy a hybrid when their next new vehicle purchase was made (the higher probability "DV" portion of "DVL"). Of that total, fully 44% of such respondents were college graduates, compared with 33% for the sample.

The argument that hybrid marketing is still targeting early adopters (visionaries), while those considering the diesel are early (majority) buyers with high rates of use of the vehicle, is supported by the nature of DVL responses for the diesel powertrain (Figures A-4–A-5). For the likelihood of choosing the diesel, there is an aggregate correlation between annual miles driven and positive DVL responses. Males, who are significantly more likely to buy a diesel than females, show a strong increase in the likelihood of purchasing the diesel when intending to drive their new vehicle more than 20,000 miles per year for the first three years of ownership. The interest of females in the diesel powertrain actually drops slightly if they intend to drive their vehicle more than 20,000 miles per year. However, elsewhere in the survey, it was shown that females are far more concerned about refueling frequency than males and are therefore more concerned about the availability of diesel fuel than males. Thus, it is quite logical that, for a female, increased driving of a diesel requires her to spend more time searching for a diesel fuel outlet, thus diminishing her interest in the diesel.

The dichotomy of interest in hybrids and diesels by level of education shows up in the patterns of DVL responses. Those with a high school education are considerably and significantly more interested in purchasing a pickup truck than those with some college or a college degree and are significantly more likely to have a positive DVL response to the question on the likelihood of buying a diesel powertrain. Among those highly interested in the diesel powertrain (high school and less education), the correlation of anticipated annual miles driven for the first three years of ownership and DVL response to the diesel powertrain is *very* powerful. This finding does suggest pragmatism in the decision of this group to buy a diesel powertrain — in other words, majority buyer decision processes. Recall also that buyers in this group were the most likely to keep their vehicles for more than six years, which is consistent with increasing the likelihood of internalizing more years of fuel savings benefits.

Nevertheless, the male respondents with a positive DVL response who have a high school education or less are still only 40% of the male respondents with a DVL response. This subgroup dominates and causes the overall positive correlation of expected annual miles traveled and probability of a positive DVL response for the diesel powertrain.

With regard to the question of "visionary" behavior by the early adopters of hybrids, the findings of Kurani and Turrentine (2004) are of considerable interest. Within their sample of 57 Californians, they interviewed eight hybrid owners, five who owned a Prius, and three who owned a Civic hybrid.

> … none of the eight hybrid owners … tracked fuel economy over long periods of time; nor were the hybrid owners any more likely than the other 49 households to know their annual fuel costs — *beyond what the vehicle will do for them without their intervention.* We emphasize that no hybrid owner we interviewed was solely or importantly interested in saving money on gasoline. Rather, they are most interested in resource conservation, reduced air pollution, new technology, and being a part of, what they perceive to be, the future. … perhaps, it is that the vehicle they perceive to be right for society, is the right vehicle for them.

This description of current hybrid owners is certainly consistent with (1) the apparent initial intent of Toyota and Honda marketing and (2) Moore's description of early adopters as persons relying on intuition and vision. However, it begs the question whether new marketing strategies emphasizing performance combined with environmental virtue are reaching more pragmatic early majority buyers and are partly responsible for the recent jump in interest in hybrids noted by Synovate Motoresearch (2004). The timing of the survey used here implies that both early adopters and some of the early majority are likely to have contributed to the indicated interest in hybrids. According to Rogers and Schoemaker (1971), 2.5% of the population are innovators, and 13.5% are early adopters, for a total of 16%. The early and late majority are 34% each, and the laggards are 16%. A 15% indication of definite and very likely interest in hybrids implies that most of these two groups are very interested in hybrids. Adding the "likely" to purchase response pushes the total to 44%, which is about the share implied by Rogers and Schoemaker to include the early majority. Thus, the survey does imply that Toyota has successfully engaged its targeted group, the early majority buyer, by its marketing of coming high-performance hybrids and current-generation Prius.

A.8 SUMMARY AND FINDINGS

The desirability of treating new vehicle markets as heterogeneous for purposes of modeling the AVID process was discussed in the context of the technology adoption life cycle. A set of subgroups for vehicle choice modeling purposes was defined — the early adopter, early buyer, and majority buyer — and compared to five other related "high-tech" technology-adoption-cycle buyer groups used by G. Moore (originally defined by E.M. Rogers). Three conflicts of the modeling assumptions and approaches proposed for AVID modeling, relative to work of others in this area of research, were discussed.

The technology adoption life cycle of G. Moore (2002) was critically examined for its relationship to the assumptions in the AVID model. By using a summary study by Mahajan and Peterson (1985), the relationship of the AVID structure to various models and theoretical perspectives from the academic innovation diffusion literature before 1985 was examined. These exercises illustrated that many of the ideas and modeling strategies implemented in the interim

AVID model and suggested for a final AVID model have counterparts in the literature on technology adoption and innovation diffusion.

Both the diesel and hybrid vehicle powertrains have recently been successful in the LDV market, but largely in different classes of LDVs. The diesel was argued to be a mature technology, but it still represents a small enough share of the market that its technology adoption life-cycle segment among the three proposed should be the early buyers, who are a pragmatic group of buyers hypothesized to correlate purchase probability to annual miles driven. The hybrid, on the other hand, was argued to still be a new, relatively unproven technology that should be of interest to the early adopter group — innovators and visionaries.

Given the context established, the results of a recent survey (designed in part with the technology adoption life cycle in mind) were examined. General consistency with the hypothetical technology life-cycle status of the diesel and hybrid was indicated. Familiarity with the two powertrain technologies was clearly powerfully related to the types of vehicles currently using those powertrains.

Education was found to create a strong dividing line of interest in the two powertrain types, with college attendance both increasing stated interest in the hybrid and decreasing stated interest in the diesel. Education was also shown to strongly correlate with a respondent's ability to identify a specific hybrid vehicle, as was income. In the aggregate, the patterns of likelihood of purchase of a diesel appeared to be logically related to NPV fuel savings, because higher rates of anticipated vehicle use correlated with a higher likelihood that a diesel would be purchased. In contrast, the stated likelihood that a hybrid would be purchased did not exhibit any correlation with anticipated annual mileage. That college education was shown to considerably increase the stated likelihood of purchase of a hybrid is consistent with the argument that early adopters are "visionaries."

Finally, 15% of respondents indicated that they would definitely purchase a hybrid or were very likely to do so in the future. This percentage is identical to the interim assumption in AVID that 15% of the new vehicle purchasing population are innovators and early adopters — consumers characterized as having preferences excessively (in terms of "rational" NDV logic) favorable to the high fuel economy of the hybrid powertrain.

A.9 REFERENCES

A.9.1 Primary

Chow, G.C., 1967, "Technological Change and the Demand for Computers," *American Economic Review* 57:1117–1130.

Davis, S.C., and L.F. Truett, 2002, *Investigation of Class 2b Trucks (Vehicles of 8500 to 10,000 lbs. GVW),* ORNL/TM-2002/49, Oak Ridge National Laboratory, Oak Ridge, Tenn.

Dodson, J.A., and E. Muller, 1978, "Models for New Product Diffusion through Advertising and Word-of-Mouth," *Management Science* 24:1568–1578.

Graham, R., et al., 2001, *Comparing the Benefits and Impacts of Hybrid Electric Vehicle Options,* Final Report 1000349, Electric Power Research Institute, Palo Alto, Calif.

Greene, D.L., and S.M. Chin, 2000, *Alternative Fuels and Vehicles (AFV) Model Changes,* Center for Transportation Analysis, Oak Ridge, Tenn. (contract DE-AC05-00OR22725), Nov. 14.

Hausman, J.A., 1979, "Individual Discount Rates and the Purchase and Utilization of Energy-Using Durables," *Bell Journal of Economics* 10:33–54.

Heraud, D., 2001, "Reviews," Microsoft "Carpoint" web site at now discontinued http://www.carpoint.com/vip/Heraud/.

Hermance, D., 2003, "Marketing Advanced Technology Vehicles," presented at Conference on The Hydrogen Transition, held at the Asilomar Conference Center, Asilomar, Calif., July 29–Aug. 1.

Hagerstrand, T., 1967, *Innovation Diffusion as a Spatial Process,* University of Chicago Press.

Horsky, D., and L.S. Simon, 1983, "Advertising and the Diffusion of New Products," *Marketing Science* 2:1–18.

Kavalec, C., 1999, "Vehicle Choice in an Aging Population: Some Insights from a Stated Preference Survey for California," *The Energy Journal* 20(3):123–138.

Kurani, K.S., and T. Turrentine, 2004, *Automobile Buyer Decisions about Fuel Economy and Fuel Efficiency*, ITS-RR-04-31, University of California Institute of Transportation Studies Report, Sept. 1.

Lackman, C.L., 1978, "Gompertz Curve Forecasting: A New Product Application," *Journal of the Market Research Society* 20:45–57.

Leiby, P., and J. Rubin, 2003, "Transition Modeling of AFVs and Hybrids: Lessons Learned," presented at Asilomar Conference, Pacific Grove, Calif., July 29–Aug. 1.

Mahajan, V., and R.A. Peterson, 1985, *Models for Innovation Diffusion,* Sage, Newbury Park, Calif.

Mahajan, V., and R.A. Peterson, 1978, "Innovation Diffusion in a Dynamic Potential Adopter Population," *Management Science* 24:1589–1597.

Malesh, T., 2000, *A Hybrid-Electric Sports Car for Every Garage?* Power Report, J.D. Power and Associates, Agura Hills, Calif.

McNutt, B., and D.E. Rodgers, 2003, "Lessons Learned," presented at Asilomar Conference, Pacific Grove, Calif., July 29–Aug. 1.

Monohan, P., and D. Friedman, 2004, *The Diesel Dilemma: Diesel's Role in the Race for Clean Cars,* Union of Concerned Scientists.

Moore, G.A., 2002, *Crossing the Chasm: Marketing and Selling Disruptive Products to Mainstream Consumers,* revised edition, HarperCollins, New York, NY.

Moore, G.A., 1995, *Inside the Tornado: Marketing Strategies from Silicon Valley's Cutting Edge,* HarperCollins, New York, NY.

ORC: Opinion Research Corporation

ORC International, 2004, CARAVAN Services, Survey of 1000 Households during May 20, 2004, for National Renewable Energy Laboratory, Golden, Colo.

Popely, J., and J. Mateja, 2004, "Green Fades as Hybrids Push Horsepower," *Chicago Tribune,* Business Section, p. 1 and 10, Jan. 18.

Plotkin, S., D. Santini, A. Vyas, J.L. Anderson, M. Wang, J. He, and D. Bharathan, 2001, *Hybrid Electric Vehicle Technology Assessment: Methodology, Analytical Issues, and Interim Results,* ANL/ESD/02-2, Argonne National Laboratory, Oct.

Robinson, B., and C. Lakhani, 1975, "Dynamic Price Models for New Product Planning," *Management Science* 21:1113–1122.

Rogers, E.M., and F.F. Schoemaker, 1971, *Communication of Innovations,* 2nd Edition, Free Press, New York.

Souder, W.E., and A. Quaddus, 1982, "A Decision-Modeling Approach to Forecasting the Diffusion of Longwall Mining Technologies," *Technological Forecasting and Social Change* 21:1–14.

Synovate Motoresearch, 2004, "Applying the Voice of the Consumer," presented at the Hydrogen Demand Workshop, Institute of Transportation Studies, University of California at Davis, June 21–22.

Toyota Motor Corporation, 2003, "Introducing High Performance Technology That's also Good for the Environment (advertisement)," *Business Week,* pp. 80–81, Aug. 18–25.

Truett, R., 2004, "DCX, GM Go Slow on Hybrids," Automotive News, p. 1. 42, July 5.

A.9.2 Secondary (discussed by Mahajan and Peterson 1985)

Rogers, E.M., 1983, *Diffusion of Innovations,* Free Press, New York.

APPENDIX B: LIST OF QUESTIONS FROM MAY 2004 ORC SURVEY ANALYZED IN APPENDIX A

Question: What is your gender?

+MALE=1
+FEMALE=2

Question: What is your ZIP Code?
[5 Digit number]
+Don't know=99999

Question: Altogether, including you and any others, how many people regularly live in this household?

+One=1
+Two=2
+Three=3
+Four=4
+Five=5
+Six=6
+Seven=7
+Eight=8
+Nine=9
+Ten or more=10
+Refused/Nr=99

Question: What was the last grade in school you completed?

+8th grade or less=1
+High school incomplete (grades 9, 10, 11) =2
+High school complete (grade 12) =3
+Some college, but no degree=4
+Associates degree=5
+College graduate/Bachelors degree=6
+Postgraduate degree, such as a Master's, PH.D., MD, JD=7
+Refused/Nr=99

<u>Question:</u> What is your age?

+18-20=1
+21-24=2
+25-29=3
+30-34=4
+35-39=5
+40-44=6
+45-49=7
+50-54=8
+55-59=9
+60-64=10
+65-69=11
+70-74=12
+75 or older=13
+Refused/Nr=99

<u>Question:</u> Was your <u>total</u> household income <u>before taxes</u> for 2003 less than $40,000 or $40,000 or more?

+Less than $40,000=1
+$40,000 or more=2
+Don't know/refused/Nr=99

<u>Question for income under $40,000:</u> Was that . . . ?

+Under $15,000=1
+$15,000 but less than $25,000=2
+$25,000 but less than $30,000=3
+$30,000 but less than $35,000=4
+$35,000 but less than $40,000=5
+Refused=99

<u>Question for income $40,000 or more:</u> Was that . . . ?

+$40,000 but less than $50,000=1
+$50,000 but less than $60,000=2
+$60,000 but less than $75,000=3
+$75,000 but less than $100,000=4
+$100,000 or more=5
+Refused [unspecified after $40,000 less or more] =99

<u>Geographic designation:</u> STATE (2-digit postal code assigned from Zip code)

See table at the end of this appendix

<u>Geographic designation:</u> METRO (assigned from Zip code)

+Metro -- In Center City of Metropolitan Area	=	1
+Outside Center City, Inside Center City County	=	2
+Inside Suburban County of Metropolitan Area	=	3
+In Metropolitan Area with No Center City	=	4
+Non-Metro -- In Non-Metropolitan Area	=	5

<u>Geographic designation:</u> Area of dominant influence (ADI)

ADI Code (See table at the end of this appendix)

<u>Geographic designation:</u> Dominant Metropolitan Area (DMA)

DMA Code (See table at the end of this appendix)

<u>Geographic designation:</u> Census Region

+North East = 1
+North Central = 2
+South = 3
+West = 4

<u>Question:</u> When you purchase your next household vehicle, do you plan to . . .

+Purchase a new vehicle=1
+Lease a new vehicle=2
+Purchase a used vehicle=3
+Do not plan to purchase vehicle=98
+Don’t know=99

<u>Question:</u> Which one of the following are you planning to purchase for your next new household vehicle?

+A small car (smaller than a Honda Accord, Chevy Malibu or Toyota Camry) = 1
+A large car (same size or larger than a Honda accord, Chevy Malibu or Toyota Camry) = 2
+A minivan = 3
+A pickup truck or large van = 4
+An SUV or sport utility vehicle = 5
+Don't know = 99

<u>Question:</u> What if the next car you purchased offered an optional, larger fuel tank that would allow you to go 50% longer between fill-ups. How much would you be willing to pay for the extra range from this larger tank?

+Responded dollar amount
+Don't know = $-1
+Refused = $-2

<u>Question:</u> Suppose you were thinking of buying a diesel car or truck. Which of the following statements would BEST describe your feelings about the availability of diesel fuel?

+It's not a problem, diesel fuel is everywhere = 1
+It's somewhat of a problem, but not a big deal = 2
+It's a problem, but not one that would stop you from buying a diesel = 3
+It's a serious enough problem that you might not buy a diesel = 4
+It's such a serious problem that you would not consider buying a diesel = 5
+Don't know = 99

<u>Question:</u> When you refuel your vehicle, which of the following do you usually do?

+Refuel conveniently when on a trip that you have to make anyway = 1
+Need to drive out of the way or on a separate trip = 2
+Don't have vehicle = 98
+Don't know = 99

<u>Question:</u> How many miles do you USUALLY have to drive out of the way or on a separate trip?

+Responded miles
+Don't know = -1
+Refused = -2

Question: How close to home is the closest place you can buy gasoline?

+Responded distance (miles)
+Don't know = -1
+Refused = -2

Question: Consider the next vehicle you plan to purchase or lease. Suppose an optional engine was available, just as good in all respects as the engine you are considering buying, but more fuel-efficient. If the engine would save $400 in fuel each year how much EXTRA would you be willing to spend for the vehicle?

+Responded amount
+Don't know = -1
+Refused = -2

Question: Consider the next vehicle you plan to purchase or lease. Suppose an optional engine was available, just as good in all respects as the engine you are considering buying, but more fuel-efficient. If the engine cost $1,200 more, how much would it have to save you EACH YEAR in fuel costs before you would be willing to buy it?

+Responded amount
+Don't know = -1
+Refused = -2

Question: Please tell me how strongly you agree or disagree with the following statement. Use a scale of 1 to 5, where 5 means you strongly agree and 1 means you strongly disagree.
"When buying a new vehicle, I want to be among the first to own a new technology."

+Strongly disagree (01) = 1
+ (02) = 2
+ (03) = 3
+ (04) = 4
+Strongly agree (05) =5
+Don't know = 99

<u>Question:</u> When or if you buy a new vehicle, how many miles PER YEAR will you drive for the FIRST THREE YEARS?

+25,000 miles or over a year = 1
+20,000 to 24,999 miles a year = 2
+15,000 to 19,999 miles a year = 3
+10,000 to 14,999 miles a year = 4
+5,000 to 9,999 miles a year = 5
+4,999 miles a year or less = 6
+Don't know = 99

<u>Question:</u> Suppose you were given an extra $1,000 that you must spend on acceleration, fuel economy and/or the ability to tow, when buying your next vehicle. How much would you spend on each attribute? You can spend all the money on one attribute or split it among two or three attributes.
. . . Acceleration

+Responded amount
+Don't know = -1
+Refused = -2

<u>Question:</u> Suppose you were given an extra $1,000 that you must spend on acceleration, fuel economy and/or the ability to tow, when buying your next vehicle. How much would you spend on each attribute? You can spend all the money on one attribute or split it among two or three attributes.
. . . Fuel Economy

+Responded amount
+Don't know = -1
+Refused = -2

<u>Question:</u> Suppose you were given an extra $1,000 that you must spend on acceleration, fuel economy and/or the ability to tow, when buying your next vehicle. How much would you spend on each attribute? You can spend all the money on one attribute or split it among two or three attributes.
. . . Ability to tow

+Responded amount
+Don't know = -1
+Refused = -2

<u>Question:</u> When you purchase a new vehicle, do you expect to sell it . . .

+Before it has 50,000 miles = 1
+When it has between 50,000 and 75,000 miles = 2
+When it has between 75,000 and 100,000 miles = 3
+When it has between 100,000 and 150,000 miles = 4
+When it has over 150,000 miles = 5
+Or, never = 6
+Don't know = 99

<u>Question:</u> There are some vehicles in the U.S. market today that have hybrid-electric powertrains that combine an electric motor and a gasoline engine to achieve a higher fuel economy than similar sized vehicles. Please name one of these hybrid vehicles, if you can.

Ford (Net)
+Escape = 01
+Ford/Ford hybrid (unspecified) = 02
+All other Ford mentions = 03
Honda (Net)
+Civic = 04
+Insight= 05
+Honda/Honda hybrid (unspecified) = 06
+All other Honda mentions = 07
Toyota (Net)
+Prius = 08
+Toyota/Toyota hybrid (unspecified) = 09
+All other Toyota mentions = 10
General Motors/GM (Net)
+Chevy Silverado = 11
+GMC Sierra = 12
+General Motors/GM/GM hybrid (unspecified) = 13
+All other General Motors/GM mentions = 14
Daimler-Chrysler (Net)
+All Daimler-Chrysler mentions = 15
+Other = 195
+Don't know/none = 199

<u>Question:</u> When you purchase your next household vehicle, how likely are you to buy each of the following? Would you say you definitely will buy it, you would be very likely to buy it, you would be likely to buy it, you would be not likely to buy it or you definitely won't buy it?
A diesel vehicle

+Definitely will buy = 1
+Very likely to buy = 2
+Likely to buy = 3
+Not likely to buy = 4
+Definitely won't buy = 5
+Don't know = 99

<u>Question:</u> When you purchase your next household vehicle, how likely are you to buy each of the following? Would you say you definitely will buy it, you would be very likely to buy it, you would be likely to buy it, you would be not likely to buy it or you definitely won't buy it?
A hybrid electric vehicle

+Definitely will buy = 1
+Very likely to buy = 2
+Likely to buy = 3
+Not likely to buy = 4
+Definitely won't buy = 5
+Don't know = 99

TABLE B-1 State, ADI, and DMA Codes

State		ADI		DMA	
State	**Code**	**Code**	**Name**	**Code**	**Name**
ALABAMA	AL	441	Abilene-Sweetwater	662	Abilene-Sweetwater
ARIZONA	AZ	419	Albany, GA (Cordele)	525	Albany, GA
ARKANSAS	AR	149	Albany-Schenectady-Troy	532	Albany-Schenectady-Troy
CALIFORNIA	CA	367	Albuquerque (Hobbs)	790	Albuquerque-Santa Fe
COLORADO	CO	255	Alexandria, LA	644	Alexandria, LA
CONNECTICUT	CT	627	Alpena	583	Alpena
DELAWARE	DE	403	Amarillo	634	Amarillo
DISTRICT_OF_COLUMBIA	DC	603	Anniston	743	Anchorage
FLORIDA	FL	265	Ardmore-Ada	524	Atlanta
GEORGIA	GA	197	Atlanta (Athens & Rome)	520	Augusta
IDAHO	ID	421	Augusta	635	Austin
ILLINOIS	IL	203	Austin, TX	800	Bakersfield
INDIANA	IN	73	Bakersfield	512	Baltimore
IOWA	IA	21	Baltimore	537	Bangor
KANSAS	KS	357	Bangor	716	Baton Rouge
KENTUCKY	KY	249	Baton Rouge	692	Beaumont-Port Arthur
LOUISIANA	LA	247	Beaumont-Port Arthur	821	Bend, OR
MAINE	ME	591	Bend	756	Billings
MARYLAND	MD	457	Billings-Hardin	746	Biloxi-Gulfport
MASSACHUSETTS	MA	363	Biloxi-Gulfport-Pascagoula	502	Binghamton
MICHIGAN	MI	145	Binghamton	630	Birmingham
MINNESOTA	MN	221	Birmingham (Gadsen)	559	Bluefield-Beckley-Oak Hill
MISSISSIPPI	MS	347	Bluefield-Beckley-Oak Hill	757	Boise
MISSOURI	MO	445	Boise	506	Boston
MONTANA	MT	3	Boston (Derry, Manchester & Worcester)	736	Bowling Green
NEBRASKA	NE	195	Bowling Green (Campbellsville)	514	Buffalo
NEVADA	NV	217	Bristl-Kngsprt-Johnsn Cty: Tri Cities	523	Burlington-Plattsburgh
NEW_HAMPSHIRE	NH	135	Buffalo (Jamestown)	754	Butte-Bozeman
NEW_JERSEY	NJ	151	Burlington-Plattsburgh (Hartford,VT)	767	Casper-Riverton
NEW_MEXICO	NM	613	Butte	637	Cedar Rapids-Waterloo-Dubuque
NEW-YORK	NY	471	Casper-Riverton	648	Champaign-Springfield-Decatur

TABLE B-1 (Cont.)

State		ADI		DMA	
State	**Code**	**Code**	**Name**	**Code**	**Name**
NORTH_CAROLINA	NC	173	Cedar Rapids-Waterloo-Dubuque	519	Charleston, SC
NORTH_DAKOTA	ND	423	Charleston, SC	564	Charleston-Huntington
OHIO	OH	257	Charleston-Huntington	517	Charlotte
OKLAHOMA	OK	279	Charlotte (Hickory)	584	Charlottesville
OREGON	OR	651	Charlottesville	575	Chattanooga
PENNSYLVANIA	PA	199	Chattanooga (Cleveland,TN)	759	Cheyenne-Scottsbluff-Strlng
RHODE_ISLAND	RI	465	Cheyenne-Scottsbluff-(Sterling)	602	Chicago
SOUTH_CAROLINA	SC	51	Chicago (La Salle)	868	Chico-Redding
SOUTH_DAKOTA	SD	89	Chico-Redding	515	Cincinnati
TENNESSEE	TN	93	Cincinnati	598	Clarksburg-Weston
TEXAS	TX	261	Clarksburg-Weston	510	Cleveland
UTAH	UT	35	Cleveland (Akron, Canton, Mansfield & Sandusky)	752	Colorado Springs-Pueblo
VERMONT	VT	243	Colorado Springs-Pueblo	546	Columbia, SC
VIRGINIA	VA	361	Columbia, SC	604	Columbia-Jefferson City
WASHINGTON	WA	229	Columbia-Jefferson City	522	Columbus, GA
WEST VIRGINIA	WV	409	Columbus, GA (Opelika)	535	Columbus, OH
WISCONSIN	WI	121	Columbus, OH (Chillicothe)	673	Columbus-Tupelo-West Point
WYOMING	WY	448	Columbus-Tupelo (West Point)	600	Corpus Christi
		433	Corpus Christi	623	Dallas-Fort Worth
		109	Dallas-Ft. Worth	682	Davenport-R.Island-Moline
		177	Davenprt-Rock Islnd-Moline: Quad Cty (Burlington,IA)	542	Dayton
		95	Dayton (Richmond,IN)	751	Denver
		241	Denver	679	Des Moines-Ames
		303	Des Moines	505	Detroit
		57	Detroit	606	Dothan
		415	Dothan	676	Duluth-Superior
		381	Duluth-Superior	765	El Paso
		39	El Centro-Yuma	565	Elmira
		371	El Paso (Las Cruces)	516	Erie
		140	Elmira	801	Eugene
		147	Erie	802	Eureka

TABLE B-1 (Cont.)

State		ADI		DMA	
State	Code	Code	Name	Code	Name
		235	Eugene	649	Evansville
		467	Eureka	745	Fairbanks
		207	Evansville (Madisonville)	724	Fargo-Valley City
		393	Fargo	513	Flint-Saginaw-Bay City
		625	Flagstaff	570	Florence-Myrtle Beach
		63	Flint-Saginaw-Bay City	571	Fort Meyers-Naples
		359	Florence-Myrtle Beach	670	Fort Smith
		71	Fresno-Visalia (Hanford & Visalia - Porterville)	509	Fort Wayne
		133	Ft. Myers-Naples	866	Fresno-Visalia
		325	Ft. Smith	592	Gainesville
		91	Ft. Wayne (Angola)	798	Glendive
		621	Gainesville (Ocala)	773	Grand Junction-Montrose
		473	Grand Junction-Durango	563	Grand Rapids-Kalamazoo-Battle Creek
		59	Grand Rapids-Kalamazoo-Battle Creek (Muskegon)	755	Great Falls
		299	Great Falls	658	Green Bay-Appleton
		315	Green Bay-Appleton (Suring)	518	Greensboro-H.Point-Winston Salem
		281	Greensboro-Winston Salem-High Point (Burlington, NC)	545	Greenville-N.Bern-Washington
		353	Greenville-New Bern-Washington (Morehead City)	567	Greenville-Spartanburg-Ashville-And
		213	Greenville-Spartanburg-Asheville (Toccoa)	647	Greenwood-Greenville
		375	Greenwood-Greenville	636	Harlingen-Weslaco-Barnsville-Mca
		601	Hagerstown (Martinsburg)	566	Harrisburg-Lancaster-Lebanon-York
		43	Harrisburg-York-Lancaster-Lebanon	569	Harrisonburg
		287	Harrisonburg	533	Hartford-New Haven
		25	Hartford-New Haven (New London)	710	Hattiesburg-Laurel
		297	Helena	766	Helena
		201	Houston	744	Honolulu
		185	Huntsville-Decatur-Florence	618	Houston
		295	Idaho Falls-Pocatello	691	Huntsville-Decatur, Flor
		83	Indianapolis (Marion, IN)	758	Idaho Falls-Pocatello
		373	Jackson, MS	527	Indianapolis
		183	Jackson, TN	718	Jackson, MS

TABLE B-1 (Cont.)

State		ADI		DMA	
State	Code	Code	Name	Code	Name
		335	Jacksonville (Brunswick)	639	Jackson, TN
		33	Johnstown-Altoona	561	Jacksonville, Brunswick
		431	Jonesboro	574	Johnstown-Altoona
		429	Joplin-Pittsburg	734	Jonesboro
		157	Kansas City (Lawrence)	603	Joplin-Pittsburg
		215	Knoxville (Crossville & Jellico)	747	Juneau
		117	La Crosse-Eau Claire	616	Kansas City
		85	Lafayette, IN	557	Knoxville
		253	Lafayette, LA	702	La Crosse-Eau Claire
		251	Lake Charles	582	Lafayette, IN
		61	Lansing (Ann Arbor)	642	Lafayette, LA
		273	Laredo	643	Lake Charles
		455	Las Vegas	551	Lansing
		379	Laurel-Hattiesburg	749	Laredo
		211	Lexington (Beattyville, Danville & Hazard)	839	Las Vegas
		101	Lima	541	Lexington
		331	Lincoln-Hastings-Kearney	558	Lima
		319	Little Rock	722	Lincoln-Hstngs-Krny Plus
		13	Los Angeles (Barston, Corona & San Bernardino-Ontario)	693	Little Rock-Pine Bluff
		209	Louisville	803	Los Angeles
		437	Lubbock	529	Louisville
		219	Macon	651	Lubbock
		113	Madison	503	Macon
		449	Mankato	669	Madison
		317	Marquette	737	Mankato
		435	McAllen-Brownsville: Lrgv	553	Marquette
		237	Medford	813	Medford-Klamath Falls
		179	Memphis (Holly Springs)	640	Memphis
		377	Meridian	711	Meridian
		127	Miami-Ft. Lauderdale (Ft. Lauderdale-Hollywood)	528	Miami-Fort Lauderdale
		111	Milwaukee (Kenosha & Racine)	617	Milwaukee

TABLE B-1 (Cont.)

State		ADI		DMA	
State	Code	Code	Name	Code	Name
		107	Minneapolis-St. Paul (St. Cloud)	613	Minneapolis-Saint Paul
		462	Minot-Bismarck-Dickinson-Glendive	687	Minot-Bismark-Dickinson
		342	Missoula	762	Missoula
		383	Mobile-Pensacola (Ft. Walton Beach)	686	Mobile-Pensacola
		327	Monroe-El Dorado	628	Monroe-El Dorado
		412	Montgomery-Selma	828	Monterey-Salinas
		181	Nashville	698	Montgomery
		245	New Orleans	659	Nashville
		9	New York (Kingston & Poughkeepsie)	622	New Orleans
		283	Norfolk-Portsmth-Newport News-Hamptn	501	New York
		385	North Platte	544	Norfolk-Portsmouth-Newport News
		439	Odessa-Midland	740	North Platte
		263	Oklahoma City	633	Odessa-Midland
		301	Omaha	650	Oklahoma City
		329	Orlando-Daytona Beach-Melbourne (Leesburg)	652	Omaha
		305	Ottumwa-Kirksville (Wapello)	534	Orlando-Daytona Beach-Melbrn
		187	Paducah-Cp Girardeau-Harrsbrg-Marion	631	Ottumwa-Kirksville
		577	Palm Springs	632	Paducah-C.Girardeau-Harrbg-Mt Vn
		417	Panama City	804	Palm Springs
		259	Parkersburg	656	Panama City
		175	Peoria-Bloomington	597	Parkersburg
		11	Philadelphia (Alntn,Atlc Cty,Bthlm,Rdng,Vinldn,Wldwd)	675	Peoria-Bloomington
		275	Phoenix (Kingman & Prescott)	504	Philadelphia
		29	Pittsburgh	753	Phoenix
		233	Portland, OR	508	Pittsburgh
		123	Portland-Poland Spring	820	Portland, OR
		161	Presque Isle	500	Portland-Auburn
		47	Providence-New Bedford	552	Presque Isle
		227	Quincy-Hannibal	521	Providence-New Bedford
		351	Raleigh-Durham (Fayetteville, Goldsboro & Rocky Mount)	717	Quincy-Hannibal-Keokuk
		469	Rapid City	560	Raleigh-Durham

TABLE B-1 (Cont.)

State		ADI		DMA	
State	Code	Code	Name	Code	Name
		459	Reno	764	Rapid City
		285	Richmond	811	Reno
		345	Roanoke-Lynchburg	556	Richmond-Petersburg
		139	Rochester, NY	573	Roanoke-Lynchburg
		165	Rochester-Mason City-Austin	538	Rochester
		119	Rockford	611	Rochester-Mason City-Austin
		67	Sacramento-Stockton	610	Rockford
		69	Salinas-Monterey	862	Sacramento-Stockton-Modesto
		23	Salisbury	638	Saint Joseph
		291	Salt Lake City (Cedar City)	609	Saint Louis
		443	San Angelo	576	Salisbury
		271	San Antonio-Victoria Leagle Pass & Kerrville	770	Salt Lake City
		15	San Diego	661	San Angelo
		65	San Francisco-Oakland-San Jose (Santa Rosa & Vallejo)	641	San Antonio
		645	Sarasota	825	San Diego
		425	Savannah (Baxley)	807	San Francisco-Oakland San Jose
		105	Seattle-Tacoma (Bellingham & Wenatchee)	855	Santa Barbra-San Mar-San Lu Ob
		321	Shreveport-Texarkana	507	Savannah
		391	Sioux City	819	Seattle-Tacoma
		389	Sioux Falls-Mitchell	657	Sherman-Ada
		17	Snta Brbra-Snta Maria-Sn Luis Obispo (Oxnard)	612	Shreveport
		53	South Bend-Elkhart	624	Sioux City
		337	Spokane	725	Sioux Falls (Mitchell)
		45	Springfield, MA	588	South Bend-Elkhart
		427	Springfield, MO	881	Spokane
		77	Springfield-Decatur-Champaign	619	Springfield, MO
		159	St. Joseph	543	Springfield-Holyoke
		75	St. Louis (Mt. Vernon)	555	Syracuse
		141	Syracuse	530	Tallahasse-Thomasville
		413	Tallahassee-Thomasville (Bainbridge)	539	Tampa-Saint Pete-Sarasota
		131	Tampa-St. Petersburg (Lakeland)	581	Terre Haute

TABLE B-1 (Cont.)

State		ADI		DMA	
State	Code	Code	Name	Code	Name
		87	Terre Haute	547	Toledo
		55	Toledo	605	Topeka
		313	Topeka	540	Traverse City-Cadillac
		451	Traverse City-Cadillac	531	Tri-Cities, TN-VA
		277	Tucson	789	Tucson (Nogales)
		269	Tulsa (Bartlesville)	671	Tulsa
		231	Tuscaloosa	760	Twin Falls
		293	Twin Falls	709	Tyler-Longview (Lfkn & Acgd)
		323	Tyler-Longview-Jacksonville	526	Utica
		155	Utica	626	Victoria
		205	Waco-Temple-Bryan	625	Waco-Temple-Bryan
		19	Washington, DC	511	Washington, DC
		153	Watertown-Carthage	549	Watertown
		115	Wausau-Rhinelander	705	Wausau-Rhinelander
		129	West Palm Beach-Ft Pierce-Vero Beach	548	West Palm Beach-Fort Pierce
		103	Wheeling-Steubenville	554	Wheeling-Stubenville
		405	Wichita Falls-Lawton	627	Wichita Falls & Lawton
		307	Wichita-Hutchinson	678	Wichita-Hutchinson Plus
		143	Wilkes Barre-Scranton	577	Wilkes Barre-Scranton
		355	Wilmington	550	Wilmington
		339	Yakima-Pasco-Richland-Kennewick	810	Yakima-Pasco-Rchlnd-Knnwck
		31	Youngstown	536	Youngstown
		125	Zanesville	771	Yuma-El Centro
				596	Zanesville